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A New Centrifuge Pellet Injector with a Screw Extruder for Steady State Fuelling

VINIAR Igor*
PELIN Laboratory, Ltd., Moscow, 125212, Russia

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Abstract

A new conceptual design of a centrifuge injector for steady state plasma refuelling by solid hydrogen isotope pellets is presented and discussed. The apparatus has three new components: a screw extruder for continuous pellet production, a new rotating curved barrel for pellet acceleration, whose entrance section is placed on the axis of the centrifuge rotor, and a new pellet chopping unit. In preliminary tests, the screw extruder with the pellet chopping unit delivered a series of about 10,000 deuterium pellets of 2 mm in size (at the rate up to 15 Hz and velocities 100–150 m/s) into the curved barrel with a 99% reliability.

Keywords:
fuelling, pellet, injector, extruder, centrifuge

1. Introduction

One of the main tasks still to be solved before the successful operation of a fusion reactor such as ITER is to refuel the plasma for long pulse lengths over 1000 s, practically for steady state operation. There are three techniques for plasma refuelling: by gas puffing, by compact toroids and by injection of pellets produced from solidified hydrogen isotopes. The key problem of the injection is to develop a reliable and much simpler pellet injector capable of injecting, in the steady state mode, an unlimited number of pellets into a plasma core. A screw extruder [1] is still most suitable for reliable pellet production in the steady state mode. Two kinds of injection techniques are now in use, those with gas guns and centrifuges. Generally speaking, pneumatic injectors are more reliable and simple devices than centrifuges, providing the pellet speed up to 4.5 km/s [2] exceeding the maximum speed for centrifuges almost by a factor of four. However, centrifuges have a major advantage over guns because there is no propellant gas to handle, process and recover. To combine the reliability of screw extruders, the simplicity of pneumatic injectors and the absence of propellant gas in centrifuges, we have suggested a new conceptual design of a centrifuge pellet injector to be discussed below.

2. Injector Design and Operating Issues

A schematic diagram of the centrifuge pellet injector and its operation principle is illustrated in Fig. 1. The main parts of the injector are an extrusion cryostat with a screw extruder and a vacuum chamber with a pellet chopping unit and a rotating curved barrel attached to the centrifuge rotor. A solid deuterium rod is pushed out from the screw extruder continuously. The chopping unit cuts off a piece of the rod and directs the pellet into the rotating barrel. The pellet is accelerated to the barrel periphery and ejected into the exaust tube.

The prime feature of the centrifuge is the entrance section of the rotating curved barrel, which is aligned with the rotational axis of the rotor. This means that the entrance section of the barrel, into which a pellet is fed,

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

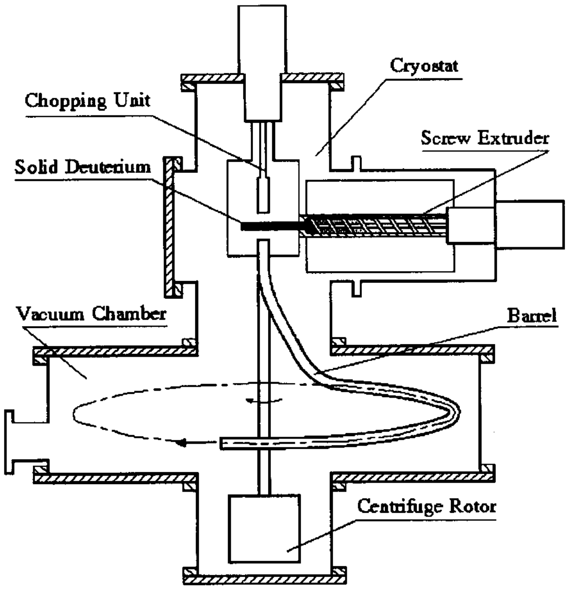

Fig. 1 A centrifuge pellet injector

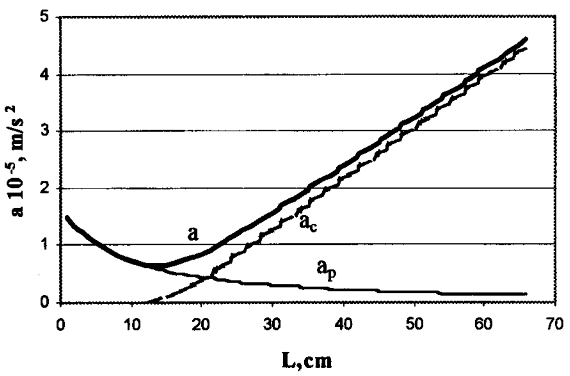

Fig. 2 A deuterium pellet (3 mm) acceleration $\boldsymbol{a}$ along the barrel length $\boldsymbol{L}$ as a sum of the pneumatic $\boldsymbol{a}_p$ and centrifugal $\boldsymbol{a}_c$ acceleration components.

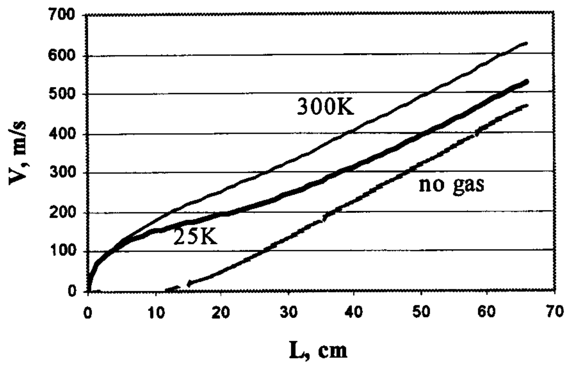

Fig. 3 A deuterium pellet (3 mm) velocity $\boldsymbol{V}$ along the barrel length $\boldsymbol{L}$ without and with gas (pressure 0.1 MPa, temperatures 25 and 300 K) acceleration.

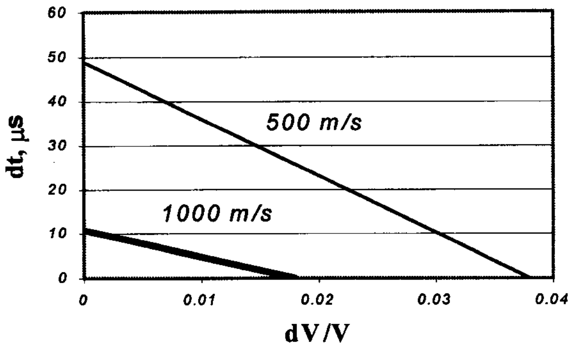

Fig. 4 The acceptable area of variation in the initial pellet velocities and the time of the pellet throw-in into the barrel entrance.

is fixed relative to the other injector units and also relative to the extrusion nozzle. Despite the rotation, the barrel entrance section does not move relative to the solid fuel rod extruded from the nozzle. This allows the adjustment of the pellet chopping unit by changing the position of the barrel entrance section, rather than of its exit section, relative to an exhaust unmovable guide tube. This considerably simplifies the injector design and performance. The curved barrel for pellet acceleration by centrifugal forces was chosen instead of an arbor or a disc [3], because during the extrusion, pellet chopping and acceleration processes, there appear gas sources due to solid deuterium ablation, which can make up 30% of the pellet mass. To eliminate oscillations in the pellet velocities from the gas inside the barrel, we intend to use a special chopping unit. This unit will cut out a pellet and create a gas pressure in the barrel inlet. The gas will accelerate the pellet effectively at the beginning of the barrel, where the centrifugal acceleration $\boldsymbol{a}_c$ is small, as is illustrated in Fig. 2. The pneumatic acceleration $\boldsymbol{a}_p$ on the periphery of the rotating barrel (the barrel length $\boldsymbol{L}$ is 60 cm) is negligible and the pellet will be accelerated by the centrifugal forces. The gas influence on the final pellet velocity $\boldsymbol{V}$ is small, as seen from Fig. 3. Here the deuterium gas in amount of 20% of the pellet mass (at temperature of 25 and 300 K and pressure of 0.1 MPa) was chosen for the acceleration of the deuterium pellet of 3 mm in diameter and length. However, the high initial pellet velocity at the entrance of the rotating barrel is useful because it reduces the pellet spread angles at the barrel exit. The acceptable area of variation in the initial pellet velocities and the time of the pellet throw-in into the barrel entrance are shown in Fig. 4.

The oscillations of the time and initial velocities should be less than 0.01ms and 18 m/s to achieve the final velocity of 1 km/s with the spread angle less than 2°. It allows injection of intact pellets because the normal velocity during the pellet blow into the exaust guide tube walls will be less than 20 m/s. By controlling the initial speed of the pellet fed into the barrel within the area shown in Fig. 4, the residence time of the pellets in this tube can be adjusted more accurately and the reliability of the intact pellet transport along the injector exhaust tube axis can be enhanced.

3. Test Results

The centrifuge injector is being manufactured now, so a limited number of preliminary tests have been carried out with the screw extruder, the chopping unit and the model curved barrel. Detailed results of the screw extruder tests were presented in [4]. A continuous 1000 s extrusion of transparent deuterium ice at a speed up to 45 mm/s was demonstrated. The chopping unit cut out pellets at frequencies from 1 to 15 Hz with a step of 1 Hz. No broken pellets were found in the diagnostic chamber after the chopping. Less than 1% of 10,000 pellets were lost during the acceleration in the model barrel by helium gas imitating the evaporated deuterium in the amount of 30% of the pellet mass. The pellet velocities were as high as 100–150 m/s depending on the gas pressure. After the acceleration in the curved barrel, all the pellets were found to be intact. The tests will be continued after the centrifuge chamber and rotor are manufactured.

4. Summary

An original centrifuge injector with a screw extruder for steady state plasma refuelling has been designed and is being patented now. The injector with one screw extruder contains 10 cm^3 of solid deuterium and is capable to produce up to 140 mm^3/s of transparent deuterium ice for pellet production. The chopping unit injects over 10,000 deuterium pellets of 2 mm diameter (at a frequency of 1–15 Hz and speed 100–200 m/s) into the fixed barrel entrance section with a 99% reliability. Tests for the pellet acceleration in the rotating barrel are being prepaired.

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