PELLET INJECTOR RESEARCH AT ORNL

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Several advanced plasma fueling systems are under development at the Oak Ridge National Laboratory (ORNL) for present and future magnetic confinement devices. These include multishot and repeating pneumatic pellet injectors, centrifuge accelerators, electrothermal guns, a Tritium Proof-of-Principle experiment, and an ultrahigh velocity mass ablation driven accelerator. A new eight-shot pneumatic injector capable of delivering 3.0 mm, 3.5 mm, and 4.0 mm diameter pellets at speeds up to 1500 m/s into a single discharge has been commissioned recently on the Tokamak Fusion Test Reactor. The so-called Deuterium Pellet Injector (DPI) is a prototype of a Tritium Pellet Injector (TPI) scheduled for use on TFTR in 1990. Construction of the TPI will be preceded by a test of tritium pellet fabrication and acceleration using a 4 mm bore "pipe gun" apparatus. A new repeating pneumatic pellet injector capable of 2.7 mm, 4 mm, and 6 mm operation is being installed on the Joint European Torus to be used in ORNL/JET collaborative pellet injection studies. A 1.5 m centrifuge injector is being developed for application on the Tore Supra experiment in 1988. The new device, which is a 50% upgrade of the prototype centrifuge used on D-III, features a pellet feed mechanism capable of producing variable-size pellets (1.5-3.0 mm diameter) optimally shaped to survive acceleration stresses. Accelerating pellets to velocities in excess of 2 km/s is being pursued through two new development undertakings. A hydrogen plasma electrothermal gun is operational at 2 km/s with 10 mg hydrogen pellets; this facility has recently been equipped with a pulsed power supply capable of delivering 1.7 kJ millisecond pulses to low impedance arc loads. A unique ultrahigh velocity concept that utilizes an intense electron beam to generate thrust by partially ablating a solid hydrogen pellet is also under development. An 0.5 m long prototype launcher operating at 30 kV, 30 amperes is scheduled for testing in August 1988.

1. Introduction

Pellet injection has produced dramatic improvements in tokamak plasma performance in several recent and ongoing experiments¹, including operation at higher densities, improved energy confinement, reduced impurity levels, and profile tailoring for auxiliary heating. Pellet injector development to support the needs of present day large tokamaks and future devices is being actively pursued at ORNL. The upcoming fusion experiments will require 2-6 mm pellets (hydrogen, deuterium, and tritium), produced at 5-10 per second repetition rates for periods ranging from several seconds to steady-state, at maximum attainable speeds, perhaps in excess of 5-10 km/s.

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2. Repetitive Pellet Injector Technology at 1-2 km/s Speeds

Both single-barrel repeating pneumatic² and multiple-barrel discrete³ shot pellet injectors which can deliver 2-6 mm hydrogen and deuterium pellets at 1-1.6 km/s speeds have been used in pellet injection experiments on the Tokamak Fusion Test Reactor. A versatile pellet injection system, consisting of three single-barrel repeating pneumatic pellet injectors mounted in one common vacuum enclosure, is presently being installed on the Joint European Torus. Individual extruders provide solid hydrogen to each gun assembly; reciprocating solenoid-driven breech tubes repetitively cut and chamber pellets. The injectors deliver 2.7 mm, 4.0 mm, and 6.0 mm size pellets at 5 Hz, 2.5 Hz, and 1 Hz repetition rates, respectively, for periods of several seconds duration; velocities up to 1.5 km/s are attainable for deuterium pellets at 100 bar propellant supply pressures (hydrogen).

A mechanical accelerator which will feature 1.5-3.0 mm pellets at 1-1.5 km/s speeds is being developed for use on Tore Supra in 1988. This injector will utilize a novel pellet forming technique capable of generating sequences of pellets for periods of 10-30 seconds. The pellet generator functions by punching pellets from a rim of deuterium frozen onto a continuously turning cryogenically cooled wheel. The pellet punch can be translated radially inward or outward with respect to the edge of the deuterium rim, thus generating pellets of the desired size. The pellets are shaped into rounded tetrahedrons or "tacos" by the punching mechanism, which is the proper shape to minimize acceleration stresses.

3. High Velocity Pellet Injector Development

The development of a high velocity pneumatic pellet accelerator, which operates with hydrogen plasma propellant, is aimed at the goal of extending the performance of present day pneumatic pellet injectors into the 2-5 km/s range⁴. The prototype accelerator consists of a vortex-stabilized arc discharge plasma generator coupled to the breech tube of a "pipe gun" pneumatic pellet injector⁵. The arc chamber is designed for arc initiation at 1-4 bar pressures, and is constructed from high temperature materials (tungsten or tantalum cathodes, graphite anode, Macor insulators). Electrical power is supplied to the arc from a 5-stage LC-line/pulse transformer supply which can produce 1 ms pulses at 5 kA currents into 0.1 ohm loads. The arc is triggered as hydrogen gas is admitted into the arc chamber; the ohmic dissipation increases the rate of rise of the gun breech pressure from 30 bar/ms to greater than 100 bar/ms. Muzzle velocities increase from 1.0 km/s to 1.3 km/s for 25 mg deuterium pellets, and from 1.3 km/s to 2.0 km/s for 10 mg hydrogen pellets; these increases represent 5-10% conversion of electrically dissipated energy to projectile kinetic energy. Muzzle velocity data for four pairs of shots with and without arc initiation are plotted vs the constant base pressure velocity calculated from the gun and pellet parameters and the maximum breech pressure in Fig. 1. Also shown are data for the repeating pneumatic injector adapted from Figs. 3 and 7 of ref. 1, and idealized gun theory performance curves for hydrogen gas at 293 K and 2000 K. It is apparent from the comparison between these data that the arc heating results in increased

propellant sound velocities, and therefore in higher sustained pellet base pressures over the acceleration interval.

Fig 1. Electrothermal gun performance.

An ablation-driven pellet launcher, powered by an intense electron beam, as is conceptually shown in Fig. 2, is the effort being pursued at ORNL with the aim of attaining pellet velocities in excess of 5-10 km/s. Composite sticks of hydrogen propellant with deuterium pellet loads are continuously loaded into a guide rail configuration. The rear surface of these pellets is ablated by a 30 A beam of 30 kV electrons generated in an e-beam source designed for high quality electron optics. External magnets provide a solenoidal magnetic field to compress and confine the e-beam. First order modelling of the acceleration, using the neutral shielding model to calculate the e-beam attenuation in the ablatant, coupled to the rocket equation and to power and mass balances at the pellet/ablatant interface, indicates that ablating 1.6 cm long propellant sticks should propel 4 mm deuterium payloads to 14 km/s. A test of prototype accelerator is scheduled for August 1988.

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Fig 2. e-beam accelerator concept.

4. The Tritium Proof-of-Principle (TPOP) Experiment

The Tritium Proof-of-Principle (TPOP) experiment is being assembled at ORNL for testing with tritium at Los Alamos National Laboratory's Tritium Systems Test Assembly later this year. TPOP is a single-shot "pipe gun" injector, similar to the unit presently in use in the high velocity development work. With the exception of the high pressure propellant valve stem tip, which is Vespel, the gun is all metal construction, thus insuring tritium compatibility. The gun and pellet injection line are to be located in a glove box, which also house all necessary tritium handling equipment. The system is designed to accommodate enough tritium for one day of operation at TSTA. Helium-3 will be cryogenically removed from the tritium to prevent blocking of the cryopumping action in the gun by non-condensable gas during pellet formation⁶. During operation, a pellet size aliquot of tritium will be metered into the barrel and frozen. The gun and glove box system has been designed to accommodate several types of fast valves and velocity booster concepts. Tritiated gas mixtures produced in the system will be removed and processed by an external vacuum system which is part of the TSTA facility.

5. References

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