CONF-860917--7

PNEUMATIC PELLET INJECTORS FOR TFTR AND JET*

S. K. COMBS and S. L. MILORA
Oak Ridge National Laboratory, P.O. Box Y,
Oak Ridge, Tennessee 37831 (USA)

CONF-860917--7

DE87 000361

ABSTRACT

This paper describes the development of pneumatic hydrogen pellet injectors for plasma fueling applications on the Tokamak Fusion Test Reactor (TFTR) and the Joint European Torus (JET). The performance parameters of these injectors represent an extension of previous experience and include pellet sizes in the range 2-6 mm in diameter and speeds approaching 2 km/s. Design features and operating characteristics of these pneumatic injectors are presented.

1. INTRODUCTION

Pneumatic hydrogen pellet injectors are being developed at the Oak Ridge National Laboratory (ORNL) for plasma fueling of large tokamaks. The repeating pneumatic injector [1], a machine gun-like device developed at ORNL, was used in the first phase of pellet fueling experiments on TFTR [2]. This injector delivered deuterium pellets at speeds ranging from 1.0 to 1.5 km/s into plasma discharges. First, single, large (nominal 4-mm-diam) pellets provided high plasma densities in TFTR (1.8×10^{14} cm^{-3} on axis in 1.4-MA ohmic plasmas); after a conversion to a smaller pellet size the pellet injector was operated in the repeating mode to gradually increase the plasma density. Up to five pellets were injected on a single machine pulse (fig. 1). Central channel line-averaged plasma densities of 1.4×10^{14} cm^{-3} were achieved. Experimental results also included central plasma densities approaching 4×10^{14} cm^{-3} and a record Lawson parameter ($n\tau = 1.4 \times 10^{14}$ cm$^{-3} \cdot$ s). These results have been described by Schmidt [3] and Milora [4].

Recently, the repeating injector was replaced by a new ORNL eight-shot pneumatic device that features three pellet sizes (3.0-, 3.5-, and 4.0-mm diameter) and speeds similar to those for the repeating gun. The eight pellets can be delivered independently to the plasma.

For the JET application, a pellet injector fashioned after the repeating pneumatic design is being developed. The versatile injector will feature three repeating guns located in a common vacuum enclosure; each gun will provide a different pellet size (2.7-, 4.0-, and 6.0-mm diameter) and will operate at repetition rates of 3-6 Hz. The TFTR and JET injectors are described below. Table I compares the physical parameters for the different pellet sizes.

* Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

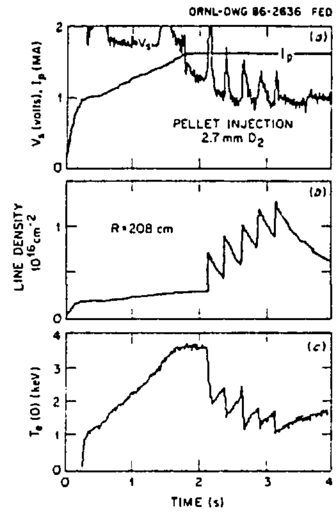

Fig. 1. Injection of five pellets into a TFTR ohmic discharge, showing surface voltage V_s, plasma current I_p, line density at R = 208 cm, and central electron temperature $T_e(0)$. R = 235 cm, a = 70 cm, B_T = 5.2 T.

TABLE I
Physical pellet parameters

Parameters	Pellet sizes: Small		⟶		Large
Nominal Size[a]					
Diameter (mm)	2.7	3.0	3.5	4.0	6.0
Length (mm)	2.5	3.5	3.5	3.5	6.0
Pellet Load					
Volume (mm^3)	14.3	24.7	33.7	44.0	170
Weight (mg)[b]	2.9	4.9	6.7	8.8	31
PV (Torr·L)	12	21	29	37	132
N(D°)	8.6×10^{20}	1.5×10^{21}	2.0×10^{21}	2.6×10^{21}	1.0×10^{22}

[a]Determined by gun barrel bore (diameter) and chamber dimension (length).

[b]The density was taken as 0.2 g/cm^3 for solid deuterium.

2. TFTR APPLICATION

2.1. Repeating pneumatic injector

The repeating pneumatic injector [1,2] is shown schematically in fig. 2. The gun-type device can operate repetitively, using a cryogenic extruder to supply a continuous stream of frozen hydrogen isotope to the gun section, where individual pellets are repetitively formed, chambered, and accelerated. Frozen pellets are formed and chambered by a punch-type mechanism in which the stainless steel gun barrel is brazed directly to a solenoid plunger. When the solenoid is activated, the knife edge of the barrel is driven into

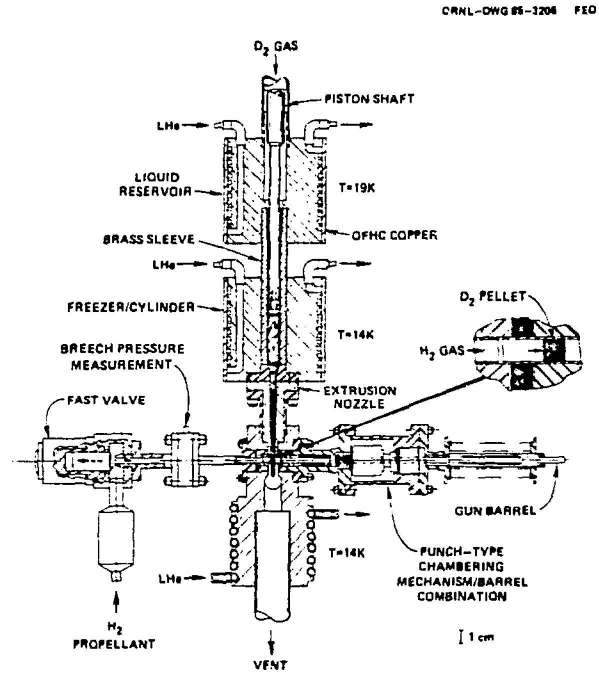

Fig. 2. Repeating pneumatic pellet injector.

the extrusion, punching out and loading a pellet. While the punch mechanism is engaged, the hydrogen propellant is admitted to the gun breech by a fast-opening magnetic valve [5] equipped with a 5-mm-diam orifice. The projectiles accelerate in a 80-cm-long gun barrel. Designs of the cryogenic extruder and the propellant valve are similar for all injectors described in this paper. Detailed descriptions of these components have been presented elsewhere [1,2,5].

A schematic of the injector installation on TFTR is shown in fig. 3. The pellets are transported to the plasma in an injection line that also serves to minimize the gas loading on the torus; the injection line incorporates a fast shutter valve and two stages of guide tubes with intermediate vacuum pumping stations. The large volume of the vacuum tanks, the fast shutter valve, and the low conductance of the guide tubes all act to limit the amount of gas ($\approx$0.04 Torr·L) that accompanies a pellet into the torus. In total, the pellet travels $\approx$4.7 m from the gun barrel outlet to the outer plasma edge. The angular dispersion in the pellet flight path was found to be negligible.

In laboratory operation at ORNL with hydrogen pellets, the injector achieved speeds as high as 1.9 km/s (1.6 km/s with deuterium pellets) at propellant pressures of up to 125 bar. Also, repetition rates of 6 s^{-1} for a pulse of several seconds were demonstrated. On TFTR, only deuterium operation was performed; the injector delivered pellets at speeds ranging from 1.0 to 1.5 km/s into plasma discharges (typical operating pressure of 70 bar). Information on the two pellet sizes used in the TFTR fueling experiments is summarized in table I.

2.2. Eight-shot injector

Whereas the repeating pneumatic injector was taken from the ORNL Plasma Fueling Development Program, the eight-shot deuterium pellet injector was developed at ORNL specifically for the TFTR fueling

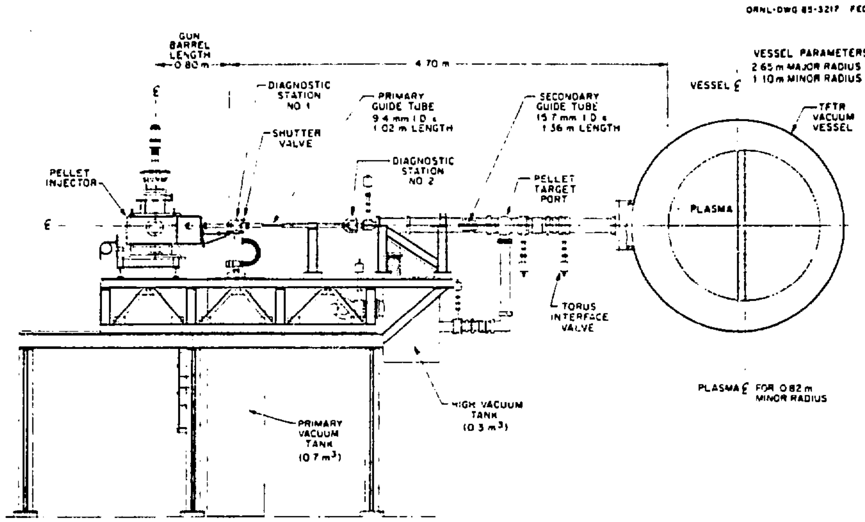

Fig. 3. Repeating injector installation on TFTR.

application and will be used for the next series of experiments. This unique device provides three pellet sizes (3.0-, 3.5-, and 4.0-mm diameter) and can deliver up to eight pellets independently to the plasma. The design combines and improves upon some features of the repeating pneumatic injector (such as the cryogenic extruder and acceleration stage) and the ORNL four-shot pellet injectors (a rotating cryogenic pellet wheel).

The multiple-shot injector is illustrated in fig. 4. A cryogenic extruder is used to supply a frozen billet of deuterium for stepwise loading of eight cylindrical cavities in a cold pellet wheel. The cavity sizes determine the pellet dimensions, with three each of 3.0- and 3.5-mm diameter and two each of 4.0-mm diameter; the length (3.5 mm) is common for all pellets and is determined by the thickness of the pellet wheel. Loading is accomplished by rotating the wheel and aligning a pellet hole with the deuterium extrusion; after sequentially filling any number of the chambers in the cold wheel, it is rotated to the firing position which aligns the pellet holes with the corresponding gun barrels. To fire the pellets, eight barrel clamp solenoids are energized simultaneously to provide sealing force around the pellet holes, and then individual propellant valves are pulsed independently to provide bursts of high-pressure hydrogen gas to accelerate the frozen pellets.

The eight-shot device occupies the same test stand and utilizes the same vacuum system as the previous injector (fig. 3). The injection line is also similar except that it contains eight tubes for each guide tube section and eight shutter valves, one set for each pellet. In tests at ORNL with deuterium, the individual guns produced pellets with speeds similar to those reported for the repeating device.

3. JET APPLICATION

A three-barrel injector based on repeating pneumatic injector technology is under development at ORNL. The device is illustrated in fig. 5, which shows the three guns, including propellant valves, the pellet chambering mechanisms, and the gun blocks. The main difference in this design and the original repeating one is the location of the punch/chambering mechanism. In the propotype, the gun barrel served as the active mechanism; however, in the new design a short section of tube (≈5 cm long) on the breech

ORNL-DWG 86-2121 FED

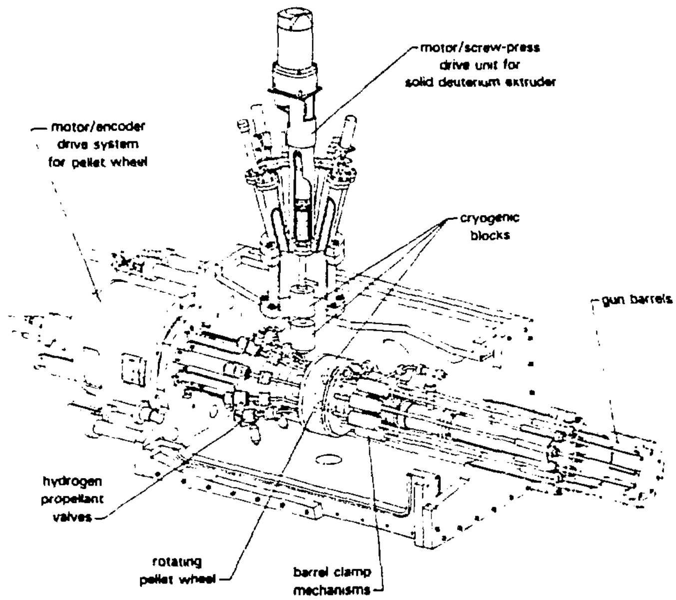

Fig. 4. Eight-shot pellet injector for TFTR.

ORNL DWG 86-2637 FED

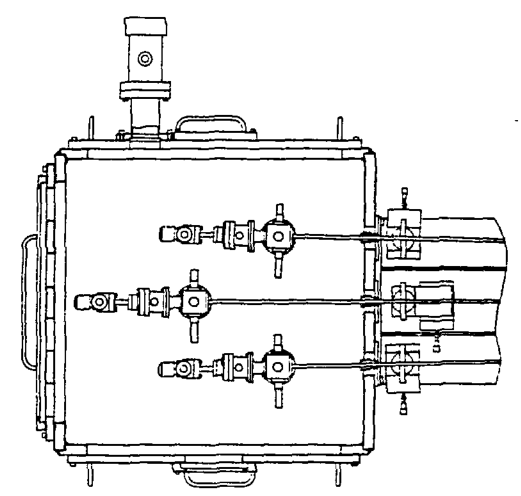

Fig. 5. Three-barrel repeating pellet injector for JET.

side of the gun acts to punch out and chamber the pellets. This change will allow the gun barrels to be aimed and positioned (fixed) accurately, which are requirements since no guide tubes are planned on the JET installation. Three separate extruders will provide frozen hydrogen to the individual gun mechanisms.

The outside two guns in fig. 5 contain barrels 2.7 and 4.0 mm in diameter (both 80 cm long). Thus, these two pellet sizes are the same as previously used for TFTR (table I). The center gun has a 6.0-mm-diam × 100-cm-long barrel. The larger pellet is provided to accommodate the larger volume in JET (five times greater than TFTR).

4. STATUS OF INJECTOR APPLICATIONS

The eight-shot injector has been installed on TFTR, and some initial pellets have been fired into plasma discharges. The construction of the JET three-barrel injector is underway. After establishing satisfactory operation of the JET injector at ORNL, it will be delivered to JET for installation and final checkout.

5. REFERENCES

[1] COMBS, S. K., MILORA, S. L., FOUST, C. R., FOSTER, C. A., and SCHURESKO, D. D., Rev. Sci. Instrum. 56, 1173 (1985).

[2] COMBS, S. K., MILORA, S. L., FOUST, C. R., SCHMIDT, G. L., and McBRIDE, T. P., J. Vac. Sci. Technol. A4(3), 1113 (May/June 1986).

[3] SCHMIDT, G. L., et al., 12th European Conf. on Controlled Fusion Research and Plasma Physics, Budapest, 2-6 September, 1985. Proceedings pp. 284, Vol. II.

[4] MILORA, S. L. et al., 13th European Conf. on Controlled Fusion and Plasma Heating, Schliersee, Federal Republic of Germany, 14-18 April 1986 (proceedings to be published).

[5] MILORA, S. L., COMBS, S. K., and FOUST, C. R. (to be published in Rev. Sci. Instrum., September 1986).