CONF-920930--11

DE93 001361

HIGH-SPEED REPETITIVE PELLET INJECTOR PROTOTYPE FOR MAGNETIC CONFINEMENT FUSION DEVICES

A. FRATTOLILLO[1], M. GASPAROTTO[1], S. MIGLIORI[1], F. SCARAMUZZI[2], G. ANGELONE[1], M. BALDARELLI[1], G. RONCI[2], S. K. COMBS[3], S. L. MILORA[3], C. R. FOUST[3], M. J. GOUGE[3], A. REGGIORI[4], G. RIVA[4], R. CARLEVARO[4] and G. B. DAMINELLI[4]

[1]Associazione EURATOM-ENEA per la Fusione, via E. Fermi, 27 (00044) Frascati (Rome), Italy.
[2]ENEA, Area Innovazione, Dipartimento Sviluppo Tecnologie di Punta C.R.E. Frascati, via E. Fermi, 27 (00044) Frascati (Rome), Italy.
[3]Oak Ridge National Laboratory*, Oak Ridge, Tennessee 37831-8071, U.S.A.
[4]CNPM/CNR, Viale Baracca, 69 20068 Peschiera Borromeo (MI), Italy.

The design of a test facility aimed at demonstrating the feasibility of high-speed repetitive acceleration of solid D_2 pellets for fusion applications, developed in a collaboration between Oak Ridge National Laboratory and ENEA Frascati, is presented. The results of tests performed at the CNPM/CNR on the piston wear in a repetitively operating two-stage gun are also reported.

INTRODUCTION

Pellet injection is presently the most effective method of sustaining plasma density and controlling its profile. Present tokamaks typically require several pellets with frequencies up to about 10 Hz, at speeds ranging between 1 and 3 km/s; fusion devices of the next generation, featuring plasma pulses on the order of minutes and temperatures around 10 keV or more, will require the development of high-speed repetitive injectors, capable of delivering hundreds of pellets at a rate around 1 Hz and with speeds up to 5 km/s or more, in order to achieve steady-state central fueling of the plasma.

At present the most suitable way of continuously producing a sufficiently large number of pellets at the desired rate is the extrusion mechanism developed by Oak Ridge National Laboratory (ORNL) (refs. 1,2), while the two-stage light-gas gun (TSG), which has been successfully used at ENEA Frascati to accelerate solid D_2 pellets at velocities up to 3.3 km/s (refs. 3,4), is the most reliable technology to launch cryogenic pellets at very high speeds.

A collaboration between the ORNL and the Frascati teams has thus been started, in the context of a cooperative agreement between the U.S. Department of Energy (DOE) and ENEA-EURATOM Association, with the aim of demonstrating the feasibility of a repetitive high-speed pellet injector by matching the Frascati TSG with the ORNL extruder. The main questions to be addressed are the maximum acceleration that an extruded pellet can withstand without breaking and the maximum repetition rate at which a TSG can operate without degrading its performance. The design of the test facility developed in collaboration by ORNL and Frascati is presented.

The crucial problem of piston wear in a TSG operating in a repetitive mode has also been addressed by an extensive study performed (in the frame of this collaboration) at CNPM/CNR; the results of these tests are reported.

THE HIGH-SPEED REPETITIVE INJECTOR PROTOTYPE

Figure 1 is a schematic drawing of the high-speed repetitive test facility designed by the ORNL and Frascati teams.

The ORNL extruder will provide a continuous supply of solid hydrogen or deuterium to the gun assembly, where a punch-type chambering mechanism forms cylindrical pellets ranging from 2 to 4 mm in diameter from the extruded ribbon, loading them into the barrel at repetition rates in the 1-Hz range. The Frascati TSG will provide hydrogen pressure pulses in order to accelerate pellets at speeds up to 3 km/s, with the same repetition rate.

The extruder operation can be controlled manually or supervised by an Allen-Bradley programmable logic controller (PLC), while the TSG will be controlled by means of a smaller PLC. The configuration shown schematically in Fig. 2 will allow the two systems to communicate in order to synchronize their operating cycles.

---

*Managed by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy.

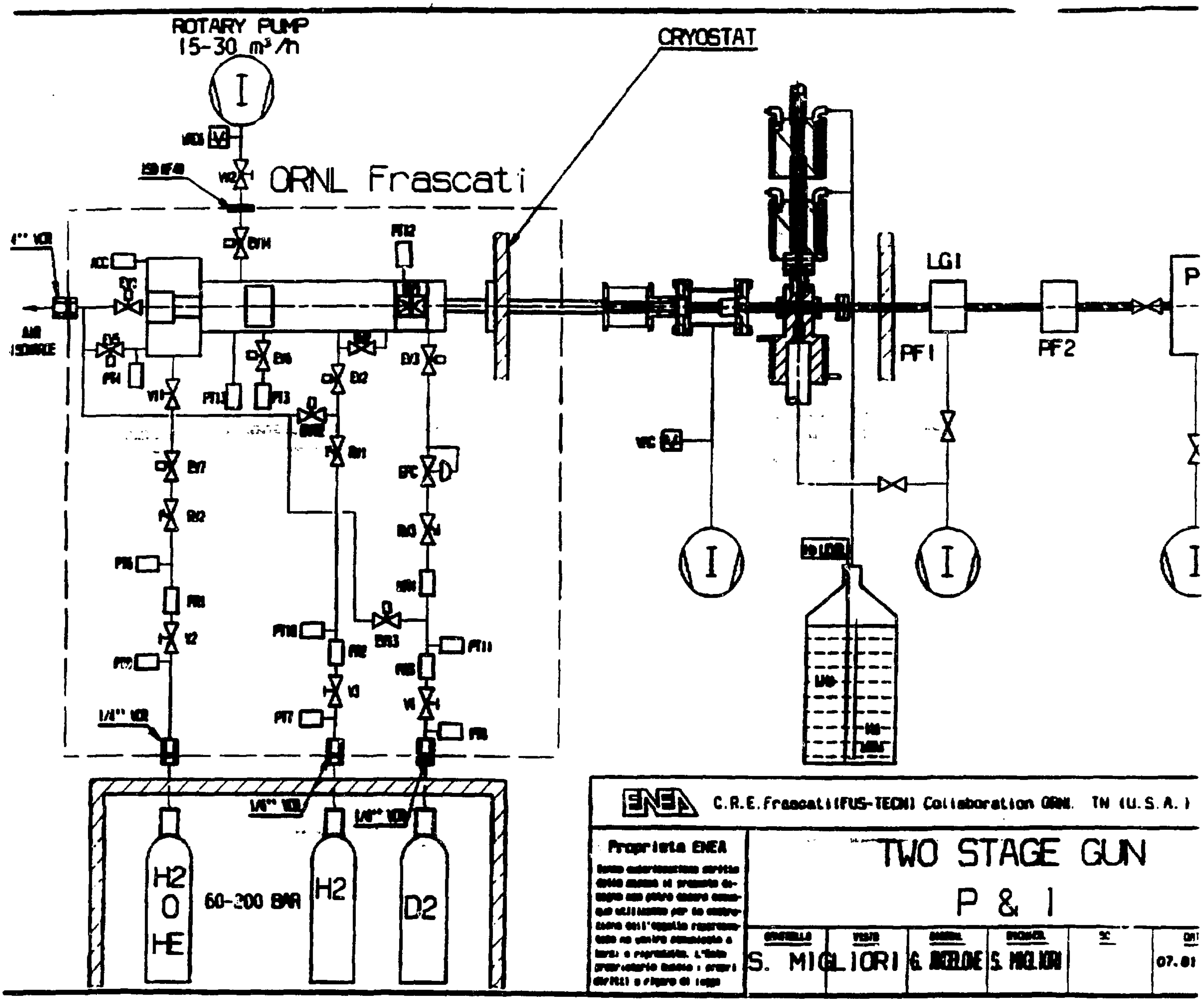

Fig. 1. Schematic of the repetitive TSG injector prototype.

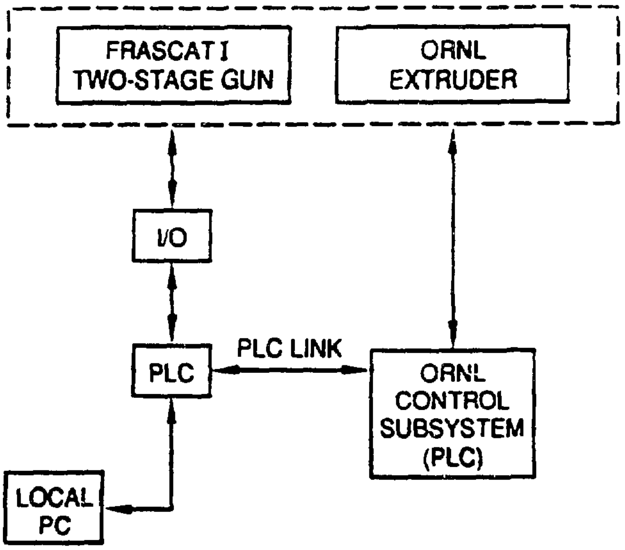

Fig. 2. Block diagram of TSG control system.

THE FRASCATI TWO-STAGE GUN

The TSG designed to operate with the ORNL extruder has the same parameters as the unit provided for the single pellet injector (SPIN) installed on the Frascati Tokamak Upgrade (ref. 5); its main parameters are summarized in Table 1. All components have been acquired and construction of the TSG is about to begin; the control system, which uses an Allen-Bradley PLC, has been assembled and is ready for preliminary testing.

Table 1. TSG parameters

First stage	
Volume, cm^3	430
H_2 driving pressure, MPa	1–2.5
Second stage	
Volume, cm^3	220
Inside diameter, mm	25
Length, mm	450
H_2 initial pressure, kPa	40–350
Piston mass, g	13

Meanwhile, a prototype with exactly the same features has been constructed and assembled at ENEA Frascati, for preliminary performance optimization in a repetitive operating mode. In a first attempt, more than 300 shots with a peak pressure of about 50 MPa have been performed in succession, with a repetition rate of about 0.5 Hz, with no significant deterioration of either performance or components. Further work is in progress in order to improve this result.

THE ORNL EXTRUDER

A schematic of the cryogenic hydrogen extruder is shown in Fig. 3 (deuterium operation is depicted and a fast valve is shown as the acceleration stage). Most of the hardware from the original ORNL repeating pneumatic pellet injector (ref. 1), previously used for repetitive fueling on the Tokamak Fusion Test Reactor (TFTR) (ref. 2), will be employed in the experiments. The extruder apparatus serves both to solidify (or freeze) hydrogen isotopes and to force feed the resulting solid to the acceleration section. A motor-driven screw press actuates a piston running in a brass sleeve. The sleeve is brazed at both ends to OFHC copper blocks. These blocks are convectively force cooled by helium (liquid and/or gas) flowing through cooling channels on their exteriors. The top block or liquefier is controlled near the triple-point temperature of the gas (~19 K for deuterium), which is below the saturation temperature of the gas feed but above the melting point of the solid. The liquid reservoir fills automatically as the gas condenses on the subcooled walls of the liquefier.

When the piston is fully retracted, the condensate drains through channels machined in the top of the brass sleeve and fills the cylindrical cavity in the second heat exchanger. The liquid eventually (within a few minutes) freezes in this region, which is maintained at several degrees below the gas triple-point temperature (~14 K for deuterium). Upon freezing of a charge, the extruder is ready to supply solid material to the acceleration section. The piston speed (and thus the extrusion time) is controlled to match the desired repetition rate for the acceleration section. A transition nozzle provides the proper size ice ribbon to the acceleration section.

The third copper block shown in Fig. 3 accommodates the acceleration device and the chambering mechanism/barrel combination unit. Like the second block, it is maintained at solid hydrogen temperatures (~14 K for deuterium). The pellet diameter is established by the inside diameter of the stainless steel tubing used for the gun barrel, which is presently 2.7 mm. The gun assembly uses a punch-type chambering mechanism in which the stainless steel gun barrel is brazed directly to a solenoid plunger. When the solenoid is activated, the

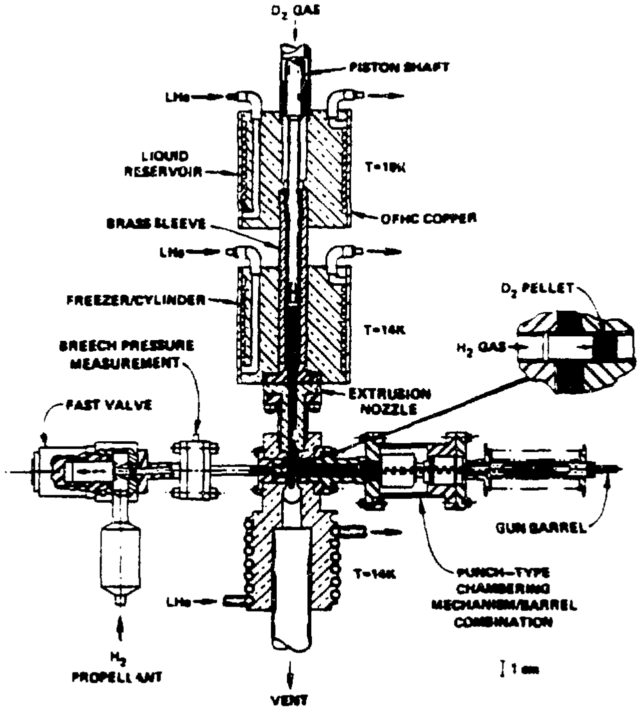

Fig. 3. Cryogenic hydrogen extruder and gun assembly (fast valve to be replaced by two-stage gun).

knife-edge end of the barrel is driven into the extrusion, punching out and chambering a pellet. While the punch mechanism is engaged, the hydrogen propellant is admitted to the gun breech via the acceleration device. An alternative chambering technique was employed on the three-barrel repeating pneumatic pellet injector used for plasma fueling experiments on the Joint European Torus (refs. 6,7); for that application a separate tube on the breech side of the gun punched out and chambered the pellets. After initial experiments, conversion to the new design can be carried out if deemed advantageous. The breech-side punch arrangement is shown in Fig. 1. The extruder will be capable of providing about 60–80 pellets for a single freezing charge. The pellet size can be changed with some mechanical modifications. For this study, the fast valve shown in Fig. 3 will be replaced by the Frascati two-stage gun.

PISTON WEAR TESTS

Single-shot two-stage injectors have been successfully tested with solid deuterium pellets at velocities up to 3 km/s and plastic pellets up to 6 km/s (ref. 8). However, the practical application of this technique requires injectors capable of continuous operation (thousands of shots at ~1 Hz). Under this aspect, it appears of primary importance to determine the characteristics and the working conditions that will minimize the deterioration of the injector and in particular of the piston, which is the most stressed component. To study this aspect of the problem, an extensive program of tests has been carried out with the CNPM gun (pump tube d = 35.03 mm, l = 2 m), aimed at finding a piston configuration for which the wear is minimized. The test conditions were the following:

- piston material: aluminum; d = 34.98 mm, l = 30–35 mm, m = 60–90 g
- test gas: air
- repetition rate: 0.1 Hz
- maximum pressure: ~1500 bar (in several shots, up to 3000 bar)
- maximum piston velocity: ~400 m/s

Aluminum was chosen because the effects of wear can be detected after a few shots with this rather soft material.

Friction and wear are minimized if a stable gas film is formed in the gap between the piston and the wall and the piston slides without oscillations. Unfortunately, these conditions are not satisfied with simple cylindrical pistons: severe wear and complete loss of performance were observed after around 50 shots. Better results were obtained when several circumferential grooves were added, but still a strong wear was observed, more evident near the edges of the piston. About 40 different shapes were tested. The best performances were obtained with the pistons shown in Fig. 4. Both pistons reached 1000 shots without loss of performance. The results are summarized below.

- Piston (a): m = 62 g; diameter after 1000 shots = 34.93 mm; maximum pressure ~ 1200 bar.
- Piston (b): m = 86 g; diameter after 1000 shots = 34.97 mm; maximum pressure ~ 1500 bar (50 shots at 2500 bar).

Note that, even though both pistons reached 1000 shots, piston (a) showed a practically constant wear

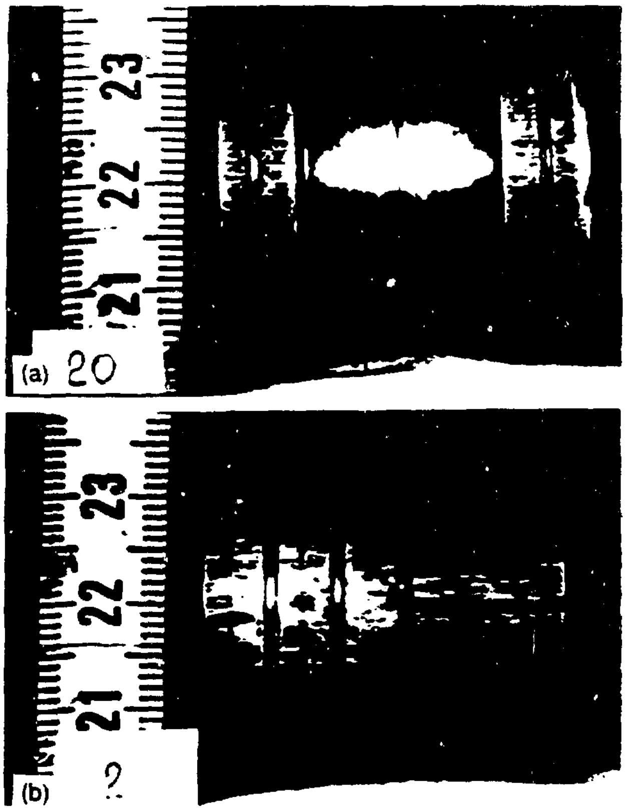

Fig. 4. High-performance pistons.

rate, while piston (b) lost about 0.01 mm in the first 100 shots and then apparently did not wear any more. A new series of tests with pistons similar to the configuration (b), but made of different materials (Ti, Cu-Be) is now under way, using hydrogen as the test gas.

REFERENCES

1. S. K. Combs et al., Rev. Sci. Instrum., 56 (1985) 1173–1178.
2. S. K. Combs et al., J. Vac. Sci. Technol. A, 4 (1986) 1113–1117.
3. A. Frattolillo et al., in: IEEE 14th Symposium on Fusion Engineering, San Diego, CA, U.S.A., September 30–October 3, 1991, IEEE, New York, 1991, p. 721.
4. A. Frattolillo et al., in: Workshop on Diagnostics for Contemporary Fusion Experiments, Villa Monastero, Varenna, Italy, August 27–September 6, 1991, pp. 999–1016.
5. A. Frattolillo et al., "High speed pellet injectors for the Frascati Tokamak Upgrade," these proceedings.
6. S. K. Combs, S. L. Milora, L. R. Baylor, C. R. Foust, F. E. Gethers, and D. O. Sparks, J. Vac. Sci. Technol. A, 6 (1988) 1901.
7. S. L. Milora, S. K. Combs, L. R. Baylor, C. R. Foust, F. E. Gethers, and D. O. Sparks, in: IEEE 14th Symposium on Fusion Engineering, San Diego, CA, U.S.A., September 30–October 3, 1991, IEEE, New York, 1991, p. 784.
8. A. Reggiori, G Riva, R. Carlevaro, and G. B. Daminelli, in: IEEE 14th Symposium on Fusion Engineering, San Diego, CA, U.S.A., September 30–October 3, 1991, IEEE, New York, 1991, pp. 737–740.