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DEUTERIUM PELLET INJECTOR GUN DESIGN*

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Abstract: The Deuterium Pellet Injector (DPI), an eight-pellet pneumatic injector, is being designed and fabricated for the Tokamak Fusion Test Reactor (TFTR). It will accelerate eight pellets, 4 by 4 mm maximum, to greater than 1500 m/s. It utilizes a unique pellet-forming mechanism, a cooled pellet storage wheel, and improved propellant gas scavenging.

Introduction

Injection of solid hydrogen isotope pellets has emerged as the lead technology for fueling magnetic fusion devices following successful experiments on ISX, PDX, and Alcator-C [1-4]. High-velocity neutral pellets can cross magnetic field lines, depositing a significant fraction of their mass in the plasma core.

The Oak Ridge National Laboratory (ORNL) is supplying a series of pneumatic pellet injectors that will be used to inject solid deuterium pellets into the TFTR [5]. The Repeating Pneumatic Injector (RPI) is currently in operation on the TFTR, and its use has resulted in record densities and confinement times on the device. The DPI is scheduled to replace the RPI in the summer of 1986.

Pneumatic pellet injectors accelerate a solid hydrogen pellet by means of a pressure imbalance due to a sudden application of pressure behind a pellet in the injector barrel. Recent injectors use high-pressure (1500-psig) hydrogen gas as propellant. The single-pellet injector and four-pellet injectors form the pellet by freezing hydrogen gas in the gun breech [6]. The RPI [7] freezes the deuterium in a separate chamber and extrudes the solid into the gun breech where a cutter forms the pellet. The pellet is accelerated when a fast solenoid valve is opened to the propellant gas reservoir. A series of chambers and pumps removes the propellant gas between the barrel muzzle and the fusion device.

Deuterium Pellet Injector Gun

The DPI is a hybrid injector using the extruder design from the RPI and an eight-barrel gun similar to that used in the four-pellet injectors. The DPI will fire up to eight right-circular cylindrical pellets (two 4.0-mm-diam by 3.5 mm, three 3.5-mm-diam by 3.5 mm, and three 3.0-mm-diam by 3.5 mm) at velocities approaching 2000 m/s. The pellet velocities are variable and can be fired independently. The propellant temperature is ambient and its pressure is a maximum of 1500 psig. The injector has a 5-min duty cycle and a lifetime of 2000 cycles.

Unique features (Fig. 1) include the combination of pellet wheel and extruder, active cooling of the pellet wheel with liquid helium, and a precise pellet wheel drive. The design features improvements to the pellet temperature isolation, propellant gas sealing, maintainability, gun thermal isolation, and operating flexibility.

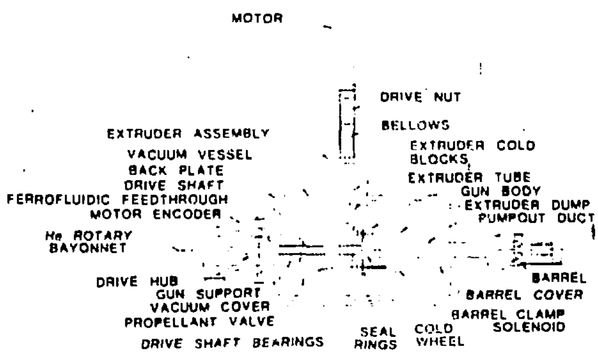

Fig. 1. Deuterium pellet injector.

To operate the DPI (Fig. 2), the gun body is cooled to 10 K to form a plug in the extruder line. The extruder piston is retracted, and the extruder is charged with deuterium. When full, the pellet wheel

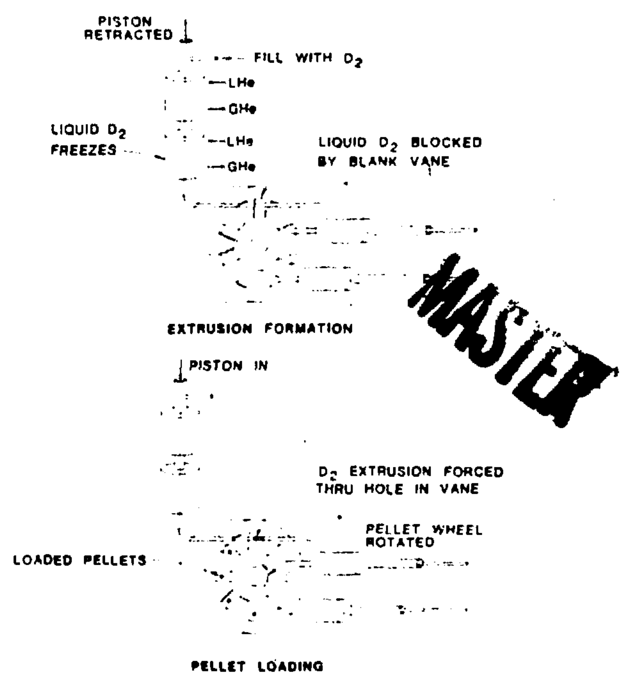

Fig. 2. Gun loading.

is rotated so that one pellet hole is aligned with the extruder line. The extruder piston is advanced to fill the pellet wheel hole. The wheel is rotated to the next position, and the process repeated until the desired pellets are formed. The wheel is next counter-

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rotated to align the pellets with the barrels. The extruder is now reloaded if necessary.

To fire, the barrel clamp solenoids (Fig. 3) are energized to seal around the pellet holes. The propellant valves are pulsed, and the pellet is accelerated.

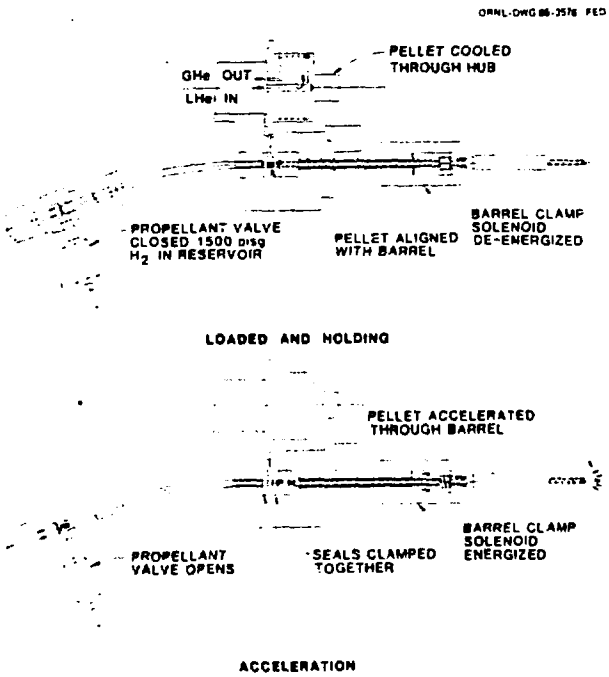

Fig. 3. Pellet firing.

The extruder utilizes a design developed by C. A. Foster [8], described by Combs [7], and proven on the mechanical and the repeating pneumatic injectors. It consists of a motor-driven screw press that actuates a piston running in a brass sleeve. The sleeve is brazed into two OFHC copper blocks. These blocks are force-cooled with liquid helium flowing in cooling channels.

The gun body (Fig. 4) consists of two OFHC copper and 304L stainless turnings (face plate and back plate) which are of brazed and electron-beam welded construction. Seals are indium wire. The face and back plates have separate liquid helium cooling passages.

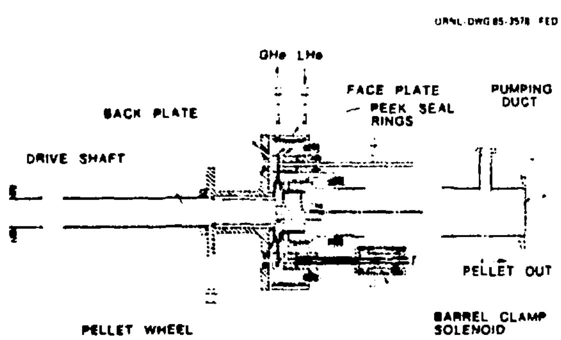

Fig. 4. Gun body.

The gun body has been designed to minimize the propellant gas blow-by from the pellet wheel and to maximize the pumping of the propellant gas from the body cavity. Barrel clamp solenoids are mounted concentrically with the barrels and are energized before the propellant valves are opened to provide sealing pressure on the polyetheretherketone (PEEK) seal rings. The body cavity is pumped by a duct which is connected to the injection line primary pumping system.

The propellant valves are flanged off the back plate in line with the barrels. These valves are Vespel-sealed, actuate in 2 ms, and have 10-cm^3 internal volumes. These valves are solenoid actuated and operate at 1500 psig.

The pellet wheel (Fig. 5) forms and transports the pellets within the gun body. The pellet wheel is sandwiched between the face and back plates, rotates

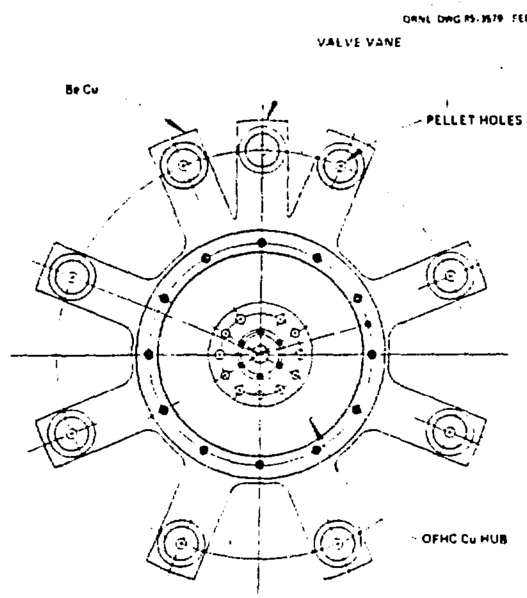

Fig. 5. Pellet wheel.

about the gun body axis, and is sealed by PEEK seal rings with steel backing rings. The wheel has nine vanes — eight for pellets and one valve vane. The vanes flex to seal against the clamped PEEK seal rings and thermally isolate the pellets. Each pellet vane has a through hole for pellet formation. This hole is smaller than the extrudate passage but larger than the barrel ID. This causes compression of the extrudate into the wheel and of the pellet into the barrel for uniform pellet consistency and for propellant gas seal.

The pellet wheel is cooled actively with liquid helium and consists of an OFHC copper hub and a beryllium-copper ring. The hub has integral cooling passages fed from the drive shaft. It is driven from the shaft by five pins and sealed with double indium O-rings for the helium inlet and exhaust.

The active cooling of the pellet wheel permits the pellets to be stored between the load and fire cycles and allows the valve vane to form a solid deuterium plug for extruder filling.

The cold wheel drive (Fig. 6) is a DC servomotor-absolute encoder coupled with a driveshaft. This rotates and accurately positions the pellet wheel while continuously tranferring liquid helium to the pellet wheel. It consists of the motor-encoder, the drive shaft, a ferrofluidic rotary vacuum seal, and a drive coupling.

Requirements of the drive are precise pellet wheel positioning and low thermal conductivity to the gun body. The pellet wheel must be positioned ±6 arc min at 5 ft-lb torque. The maximum torque is 19 ft-lbs, limited by buckling in the pellet wheel vanes. The drive shaft must minimize axial thermal conduction between 273 K at the ferrofluidic seal and 10 K at the gun body.

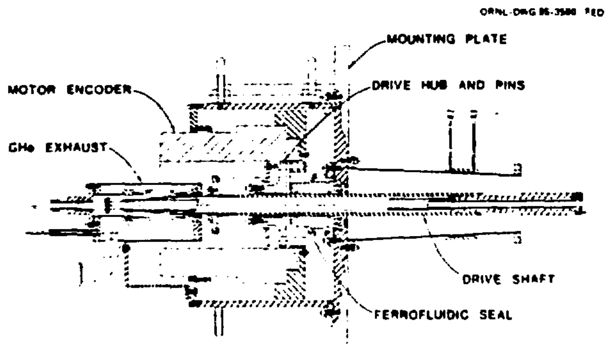

Fig. 6. Cold wheel drive.

The motor-encoder is a DC servomotor–14-bit absolute encoder package purchased from BEI Electronics, Little Rock, Arkansas.* It is a turnkey package with a unitized motor-encoder and remote drive and logic. The motor has 23 ft-lbs torque, ±79 arc s accuracy, and 180°/s acceleration. The control logic is programmable. The motor-encoder package is 11.6 in. OD by 6 in. ID and is mounted concentric to the drive shaft. This package was chosen due to its low backlash, ease of coupling to the drive shaft, and turnkey package.

The motor-encoder has been extensively modified to remove Teflon to comply with requirements of the Princeton Plasma Physics Laboratory (PPPL). Radiation-sensitive components have either been replaced or made accessible to enable the unit to operate to a neutron fluence of 2×10^{12} n/cm^2.

The drive shaft transmits the torque from the motor-encoder to the pellet wheel, centers the wheel in the gun body, and is the liquid helium feedthrough to the pellet wheel. It is supported between a bronze bushing in the gun body and the drive coupling off the motor bearings. The shaft is fixed axially at the pellet wheel and is free to float axially at the motor.

The shaft is fabricated of concentric tubes. An inner tube forms a bayonet fitting for the liquid helium. The transfer line is stationary, and the inner tube rotates over it. The gaseous helium exhausts through an annulus over the inner tube. The room-temperature shaft coupling and ferrofluidic feedthrough are isolated with a vacuum annulus. The gaseous helium return vapor traces the drive shaft. The shaft OD is 1.5 in. The shaft stiffness is 4.4×10^{-3} degrees/ft-lb with a thermal load of 4.5 W into the gun at 1-L/h helium flow. The shaft is driven through clamp rings from the drive coupling.

The DPI has five independent liquid helium cooling circuits. Each has a control valve and heaters for temperature control. The DPI receives liquid helium through a transfer line entering the extruder flange. An internal jumper transfers liquid to the back plate where an external transfer line conducts helium to the pellet wheel. Solenoid cutoff valves are on each exhaust line.

All subsystems are mounted on either the cryostat rear flange or on the extruder flange. A minimum of connections is made between these modules. This allows major subsystems to be removed and repaired or assembled on the workbench. Large access ports are located in the injector cryostat sides. The dc servomotor and driveshaft may be removed with a minimum of disassembly of the injector.

Summary

The DPI has been designed to combine desirable features of the four-pellet injectors and the RPI. It features improved pellet isolation and storage techniques, improved propellant gas sealing, maintainability, and operating flexibility. The DPI will provide flexible operation while injecting high-velocity deuterium pellets into TFTR.

Acknowledgments

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