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Abstract

A tritium pellet injector (TPI) system has been designed for the Tokamak Fusion Test Reactor (TFTR) Q ~ 1 phase of operation. The injector gun utilizes a radial design with eight independent barrels and a common extruder to minimize tritium inventory. The injection line contains guide tubes with intermediate vacuum pumping stations and fast valves to minimize propellant leakage to the torus. The vacuum system is designed for tritium compatibility. The entire injector system is contained in a glove box for secondary containment protection against tritium release. Failure modes and effects have been analyzed, and structural analysis has been performed for most intense predicted earthquake conditions. Details of the design and operation of this system are presented in this paper.

Introduction

A TPI system has been designed to meet fueling requirements during the Q-1 phase of operation of the TFTR. These requirements include the need for up to eight 4-mm x 4-mm cylindrical pellets to be delivered to the torus at velocities in the range of 1000 to 2000 m/s. The gun chosen for this purpose is a pneumatic type that utilizes high-

pressure hydrogen as a propellant. Minimization of the amount of tritium required to produce the pellets was an important consideration in choosing the radial gun presented here. The TPI systems were designed to be compatible with, and utilize the same technology as, other systems that had already been adopted for use in the TFTR facility. Major TFTR interfaces include the tritium storage and delivery system (TSDS) for tritium supply, the torus cleanup system (TCS) for tritium control, and the TFTR central instrumentation control and data acquisition (CICADA) system for control of TPI during fueling operations. This paper describes the major TPI subsystems, with particular attention being given to those aspects that are unique to this system.

TPI Subsystem

Gun

The TPI gun, shown in Figs. 1 and 2, has a central extruder and magazine block, which forms a single billet of solid tritium (~3000 Ci). Pellets are extracted from the billet with slides and carried to the radially configured gun blocks for firing. In addition to minimizing the tritium inventory,

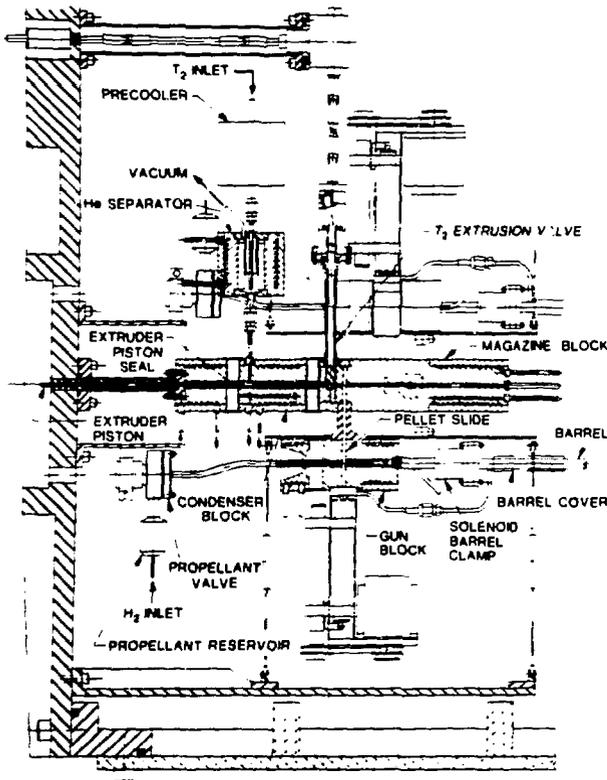


Fig. 1. TPI gun assembly.

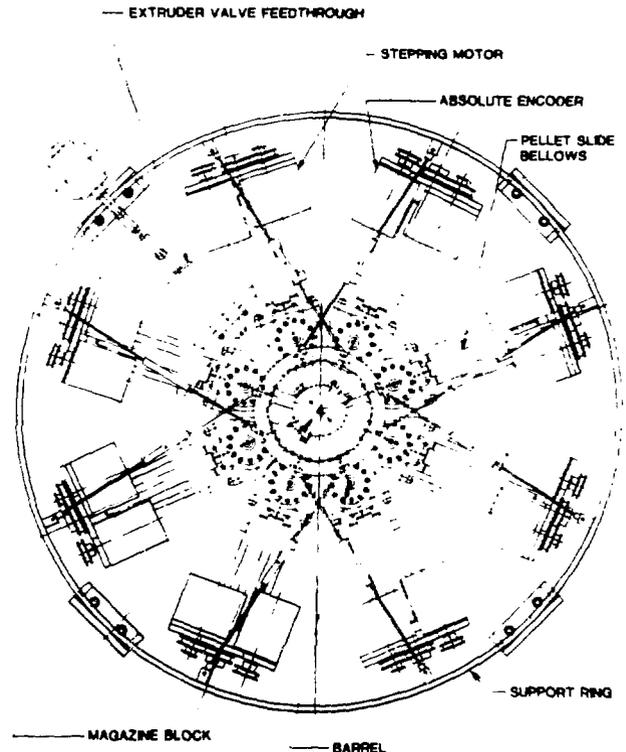


Fig. 2. TPI gun schematic.

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this configuration allows for independent firing of individual pellets without any possibility of propellant leakage to other barrels. It also provides thermal isolation between condenser, magazine, and gun blocks so that each can be operated at a different temperature.

In the formation of the tritium billet, (Fig. 3) liquid tritium (30 K, 300 torr) is drained from the helium separator into the condenser block with the extrusion valve closed. The blocks are then brought to the extrusion temperature (~15 K), and the solidifying tritium is compressed against the closed extrusion valve with the ramrod. Pellets are formed by extruding the billet through holes in the pellet slides, which are lined up concentrically with the centerline of the magazine block. (Figure 3 shows all holes the same size, but both the pellet diameter and length can be different for each slide.) Pellets are sheared out of the extrudate, by withdrawing the slides, and carried to a holding position in the gun blocks. This position is off the centerline of the barrel, where they can be held for an extended period of time at $T < 10$ K. During this period, unused tritium is removed by warming the magazine and extruder block and using the helium separator as a cryopump to collect it. Tritium can be held here for the next shot, returned to the feed system, or even returned to TSDS prior to firing pellets. Just prior to firing, the pellets are moved to the centerline of the barrel, and the barrel clamp solenoids are energized, sealing the barrel against the slides to prevent propellant leakage. Energizing the propellant valve releases high-pressure hydrogen (10 mL, 1000 to 2000 psi), which accelerates the pellet to the desired speed.

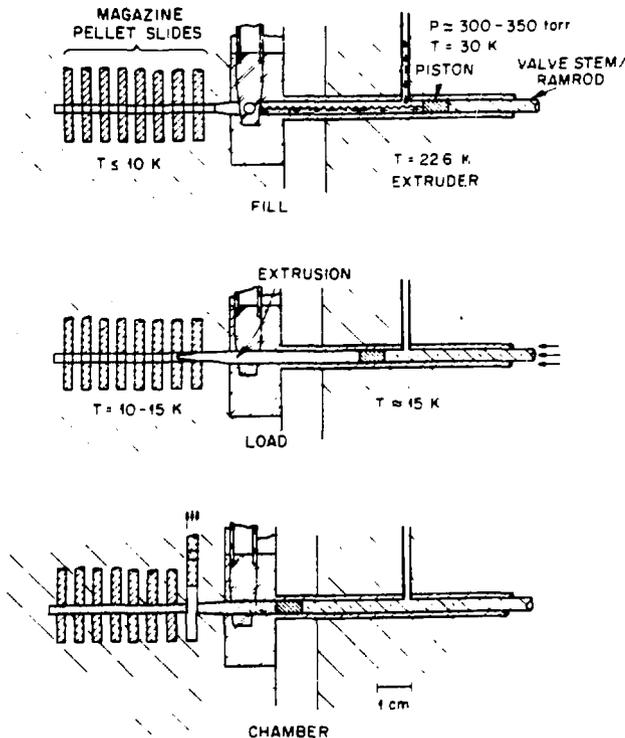


Fig. 3. TPI Pellet formation sequence.

Several key mechanical components have been adopted from previous guns [1,2]: the barrel clamp mechanism, propellant valves and reservoirs, precooler, and extruder. The pellet slide mechanisms (new to this design) are driven by worm gears actuated by stepper motors. Slide positions are determined with absolute encoders. The gun is mounted in a cubical guard vacuum chamber with removable sides, top, and bottom for easy access. The entire gun assembly and all feed-throughs are mounted on the back panel to ease the assembly and disassembly process. Components that could require maintenance are designed for easy removal.

Injection Line and Vacuum

The injection line is essentially identical to the one utilized in the deuterium pellet injector (DPI) design [2,3]. Designed to keep the propellant from reaching the torus, it consists of three vacuum stations separated by two sets of guide tubes, as shown in Figs. 4 and 5. The primary and secondary systems are further separated from each other by valves that close within ~10 ms of firing. These systems each have a large chamber to collect propellant during firing. The chambers are sized to accept propellant from all eight guns simultaneously, without choking the vacuum pumps. The tertiary vacuum station pumps directly on the region in front of the torus isolation valve. This pump picks up gas produced when test pellets are fired into a closed valve and ensures the low pressure criterion required to open this valve.

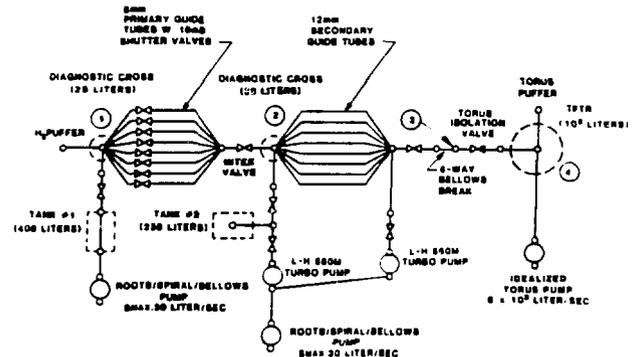


Fig. 4. Vacuum system schematic.

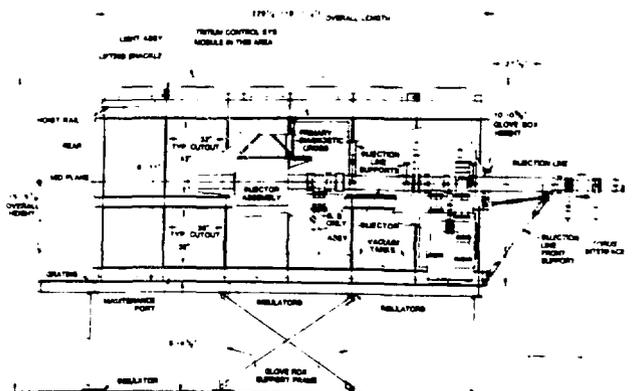


Fig. 5. TPI partial assembly elevation.

Components of the vacuum system, shown in Figs. 5 and 6, were chosen to be tritium compatible [4], whenever possible. Rough pumping on the primary and secondary chambers is achieved by a combination of three pumps in series: a two-stage roots pump is backed by a spiral pump, followed by a two-stage bellows pump. The maximum speed of this system is 30 L/s, and the maximum operating pressure is 10 torr. The secondary and tertiary systems achieve high vacuum through the use of magnetic bearing turbomolecular pumps. This system is capable of picking up ~5000 torr-L of hydrogen propellant, while releasing only 0.23 torr-L to the torus.

As seen in Figs. 5 and 6, the pumps and piping are located on one side of the glove box, where they are easily reached during maintenance. Pumps and other equipment can be transported the length of the box through an unobstructed region on the other side of the box. The maintenance trolley, shown in Fig. 6, is used to move equipment under the gun. Pump oil is changed by transferring it to a removable container, using a positive displacement pump, followed by filling from an oil reservoir attached with a quick-disconnect fitting to the outside of the box.

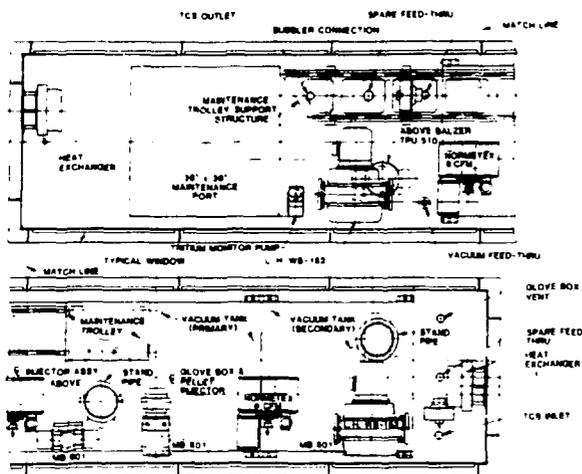


Fig. 6. Plan section of vacuum pump locations.

Gas Manifold

Fuel is supplied to the gun with a gas manifold system, shown schematically in Fig. 7. The TPI is expected to fire ~2000 shots, including both tests and fueling, with only ~10 of these being pure tritium fueling shots. Over one-half will be pure deuterium, and the balance will be mixtures containing from 0.1% to pure tritium. The manifold can be used to produce mixtures by filling calibrated volumes at known temperatures to given pressures, followed by mixing in a loop with a bellows pump. This pump can also be used to pump gas to and from the gun and the TSDS. This system utilizes all metal components to ensure integrity, cleanliness, and tritium compatibility. A vespel insulating break is located in the tritium feed line just inside the box for electrical isolation. All valves are air operated normally-closed with position-sensitive microswitches to verify operation.

Tritium received from TSDS is expected to contain >0.1% ^3He . Proper gun operation, however, requires <0.001% ^3He to prevent blocking of the cryopumping action of the extruder [5]. A cryogenic ^3He separator, shown in Fig. 8, is located between the precooler and the extruder (Fig. 2). The separator has a large volume to prevent ^3He from building up to a high pressure while tritium is being cryopumped. After the separator is filled, ^3He is drained off to the primary vacuum system leaving nearly pure tritium.

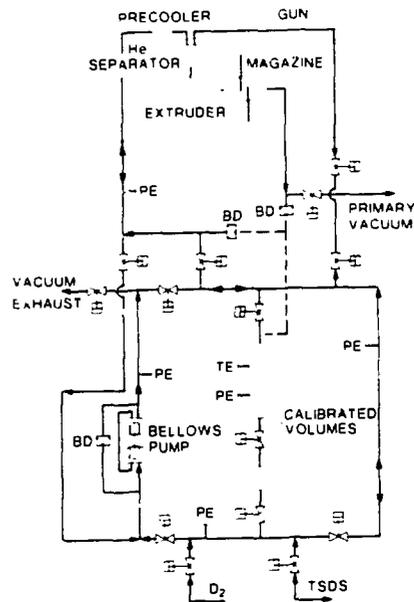


Fig. 7. Tritium supply manifold.

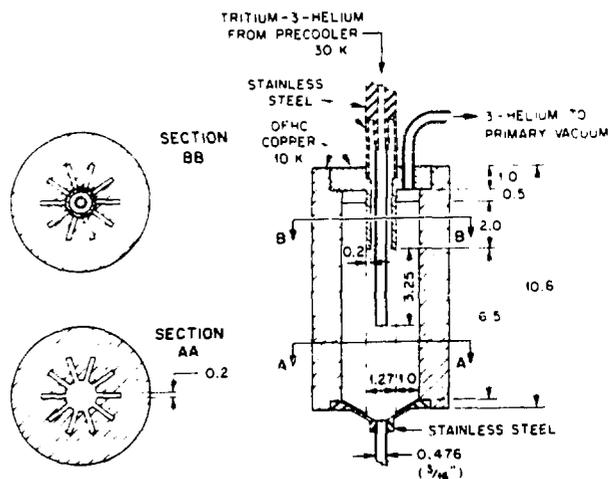


Fig. 8. Tritium and ^3He separator.

Glove Box

The glove box enclosure, shown in Fig. 5, provides both secondary containment for tritium and structural support for all elements of the TPI system that it contains. The gun, injection line, and gas manifold are suspended from the ceiling of the box. The box is designed to conform to the standards of the TFTR tritium system [6]. It has its own pressure and temperature control systems. Two cranes, located on opposite sides and suspended from rails that run the length of the box, can be used to lift and move all equipment in the box. Glove port windows, with tenting flanges, cover both sides of the box. The floor of the box contains a window, the maintenance port, for removal of heavy equipment. Small items can be transferred through a bag port at the rear of the box. Interfaces are generally located as follows: instrumentation and control in the rear panel, electrical in the forward panel, ventilation and TCS in the floor, and TSDS in the ceiling.

The glove box structure is electrically isolated from the stand, the torus, and all other interconnecting tubulation with insulating breaks to break eddy current loops. The stand also has insulators for this purpose.

Using the most intense earthquake criteria, a finite element analysis was carried out for the fully equipped glove box and stand for static load, lifting, and seismic cases [7]. It was found that both the maximum stress and the relative displacement of structural elements were at acceptably low levels in all cases.

Instrumentation and Control

Operation of the TPI is accomplished primarily through the use of a programmable logic controller (PLC) [8]. Some critical elements of the system that require tight feedback control, such as the temperature of various gun blocks, have their own dedicated controllers with setpoints coming from the PLC. Hard wired relay controls are used to place specific elements in safe conditions, independent of the PLC, should certain problems be detected in the tritium vacuum or cryogenic systems. Control of the fueling operation is initiated and monitored by a remote VAX computer, which controls TPI through the PLC. The TPI can also be operated locally through the PLC.

Safety Analysis

A preliminary safety analysis showed that there are no major health or safety issues which would effect either the performance or schedule of the TPI system. Analysis of failure and effects indicated that no accident originating within TPI would release radioactivity to the test cell. Accidents originating outside TPI and penetrating the TPI enclosure would not lead to major off-site doses. An addition to the TFTR final safety analysis report will be prepared for TPI, and a tritium readiness review will be held before TPI is operated.

Project Status

Title II design of TPI is ~80% complete and the project is on hold. Restart of the project will be paced by the schedule for the Q~ phase of TFTR operation. The present schedule indicates delivery for installation during July 1988 [3].

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