TFTR TRITIUM VALVE FOR PULSED GAS FEED, TEST RESULTS*

J. W. Rockensies and B. Sue

Grumman Aerospace Corporation
Bethpage, N. Y. 11714

R. Walls

Princeton Plasma Physics Lab
Princeton, N. J.

Summary

This paper presents the results of a test program currently being conducted at the PPPL (Princeton Plasma Physics Lab) to evaluate the design of an engineering-model valve to be used for controlling pulsed-feed tritium injection scenarios into the TFTR (TOKAMAK) torus.

The test program is designed to characterize the performance of the valve and determine throughput modulation and repeatability. Testing is being performed primarily with helium gas, but the capability to test with argon, deuterium, and hydrogen gases is available in order to provide an adequate data base to extrapolate to the tritium case. The TFTR proposed tritium feed system line configurations have also been simulated to evaluate dynamic effects of the pulsed feed.

Introduction

The TFTR is the first United States device planned to demonstrate the fusion of deuterium and tritium at reactor level power densities in magnetically confined toroidal plasma. The tritium valves will be utilized to admit tritium (and other working gases such as H_2, D_2, Ar, He, N_2, Ne) into the torus according to a predetermined schedule. They must be high-quality, high-response, long-life, remotely operating valves that can withstand radiation, magnetic fields, periodic bakeouts and discharge cleaning. The valves must be repeatable and must have the capability to provide modulated flow during the injection schedule.

The design of the tritium inlet valve was initiated by the Grumman Aerospace Corporation in January 1977. Alternate design concepts were evaluated, and the principle of using piezoelectric crystals to control activation and flowrate modulation was selected as the prime approach. A commercially available valve (Veeco PV-10) currently used on the PLT (Princeton Large Torus) has successfully demonstrated the feasibility of this principle at low throughput ranges. However, the procurement of a valve capable of providing the maximum throughput requirements and modulation range needed for TFTR was not available. An engineering model valve to evaluate the feasibility of meeting TFTR requirements was therefore designed by Grumman and a preliminary design review conducted on March 1, 1977. Three test valves were fabricated, and the test program initiated in early June.

Description

The valve has been designed to provide continuously variable flow over a range of 410 torr-liters/sec, with an inlet pressure of 750 torr, down to 50 torr-liters/sec with a run-to-run repeatability of ±2% over the entire modulation range, 100-millisecond injection period; it utilizes piezoelectric crystals to control actuation and throughput modulation. Based on the use of three tritium inlet valves to the torus, a total maximum throughput of 1228 Tl/sec is obtained. Flowrates under 50 torr-liters/sec will be controlled by a smaller, currently available, Veeco PV-10 piezoelectric valve. Additional design criteria [illegible] the valve actuate in 5 milliseconds or less and be capable of providing sealing capability in the range of 1×10^{-8} scc/sec, utilizing helium as the test medium at 1 atmosphere inlet pressure. In order to achieve this internal leakage requirement, a variety of sealing configurations were evaluated including polyimide seats and a stainless steel plunger, brass seats and polyimide plungers, and brass seats used in conjunction with plungers incorporating several different types of Viton seals.

Further overall technical requirements are summarized as follows:

- Maximum instantaneous throughput 410 Tl/sec at 300°K with an inlet pressure of 750 torrs
- Response time 5 milliseconds full-closed-to-full-open or full-open-to-full closed
- Bakeable in situ to 120°C (closed)
- Maximum external leakage 1×10^{-9} scc/s using helium as the leak detection medium at 1 atmosphere pressure differential
- Maximum internal leakage 1×10^{-8} scc/s using helium as the leak detection medium at 1 atmosphere pressure differential
- Valve shall fail-safe to the closed position
- Minimum cycle life 10^5 actuations (without replacement of parts)
- Valve to operate in a magnetic field of 3000 gauss
- Magnetic stray field produced by valve 5 gauss at 1 foot
- All valve materials to be capable of absorbing a cumulative radiation dosage of 10^5 rad without degradation which affects valve function and/or reliability.

Valve Design

The basic valve design incorporates two cantilevered piezoelectric crystals actuating a poppet as shown in Fig. 1. In principle when a voltage is applied across the crystals,

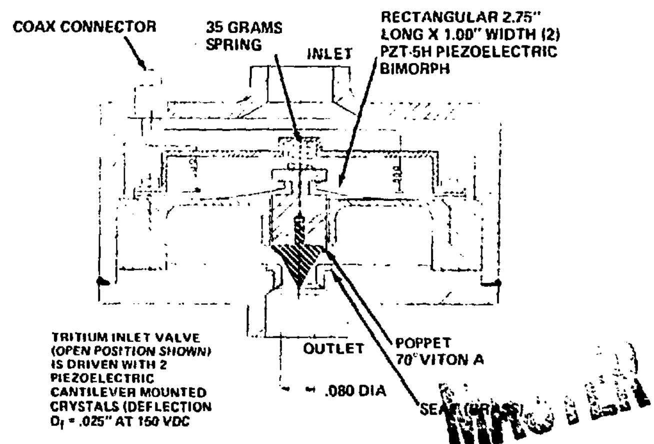

Fig. 1

*This work was supported by U.S. Energy Research and Development Administration Contract E(11-1)-3073 at Princeton University, Princeton, New Jersey they will deflect in proportion to the magnitude of the applied voltage, thereby raising the poppet off the seat and initiating flow. By varying the applied voltage the throughput can then be modulated. The crystals utilized in the test program were procured from the Vernitron Piezoelectric Division and are 2.75 inches long, 1.0 inch wide and 0.021 inch thick. Crystal sizing was selected on the basis of an analysis of the force required to overcome a delta pressure loading on the seal of 760 torr plus the weight of the poppet. The following equations are utilized in determining the force required for force actuation and throughput magnitude.

$$F_T = P_i A_s + F_w \text{ (weight of poppet)} \quad (1)$$

Where:

F_T = Total force on poppet

P_i = Upstream pressure

A_s = Seal area

An orifice diameter of 0.08 inch was selected as being adequate for providing a maximum instantaneous throughput of 410 Tl/sec based on analysis using equation (2).

Where:

Q = Throughput Tl/sec

$\gamma = \dfrac{C_p \text{ (specific heat at constant pressure)}}{C_v \text{ (specific heat at constant volume)}}$

$k = 1.03 \times 10^{-22}$ torr liters/°K (Boltzman Constant)

T = Temperature °K

$\dfrac{Am}{M} = \dfrac{\text{Avogardo's number}}{\text{Molecular weight}}$

$P_r = \left(\dfrac{2}{\gamma+1}\right)^{\gamma/(\gamma-1)}$ (critical pressure ratio for adiabatic flow through an orifice)

P_i = Upstream pressure in torr

C_d = Orifice coefficient = 0.6

A_f = Flow area (cm^2)

$$Q = \left[\frac{2\gamma k\ T\ Am}{M(\gamma-1)}\right]^{1/2} P_r^{1/\gamma}\left[1-P_r^{(\gamma-1)/\gamma}\right]^{1/2} P_i C_d A_f \quad (2)$$

The required force from equation (1) was calculated as approximately 35 grams. Based on design data provided by Vernitron, the force produced by the crystal selected is in the range of 50 grams per crystal thereby providing a total of 100 grams for the two crystals. Modulation of throughput is obtained by varying the applied voltage from approximately 225 volts to approximately 140 volts which corresponds to a throughput range of approximately 490 Tl/sec to approximately 12 Tl/sec (using helium as the test medium at an inlet pressure of 760 torr).

Sealing Configurations

Various sealing configurations were evaluated during the course of the test program, the results of which are summarized as follows:

The initial design of the sealing configuration incorporated a stainless steel ball encapsulated in a plunger, sealing against a polyimide conical seat (Fig. 2A). Polyimide was selected for this application because of its capability to absorb radiation in the range of 10^8 rads without degradation, which is consistent with close-coupling the valve to the torus. However, a subsequent decision not to close-couple the valve to the torus, but instead to mount it outside the protective igloo wall to provide the capability of hands-on maintenance, has reduced the radiation level to 10^5 rads. This lower level now makes the use of a soft sealing material such as Viton a more viable concept for the sealing configuration.

A second design using a tapered polyimide plunger sealing in a sharp lip brass seat (Fig. 2B) was tried and again leakage proved to be excessive.

It was found that the only means by which the internal leakage requirement could be achieved was by using Viton seals. Even with these seals leakage was recorded in 10^{-7} scc/sec range as compared to the requirement of 10^{-8} scc/sec. A flat-face plunger sealing against a sharp lip brass seat (Fig. 2C) was the first soft seal configuration tried. A light spring was incorporated in the design to slightly preload the poppet in the closed position to increase its sealing integrity. With this configuration the leak rate was significantly improved, but the modulation capability of the valve diminished to such a degree that the valve would function basically only as an on-off valve.

The poppet was then modified to incorporate a Viton ball seal (Fig. 2D) which improved the modulation capability but still did not provide adequate repeatability, particularly at low throughput levels. A further modification was made which incorporated a conical Viton poppet (Fig. 2E) which

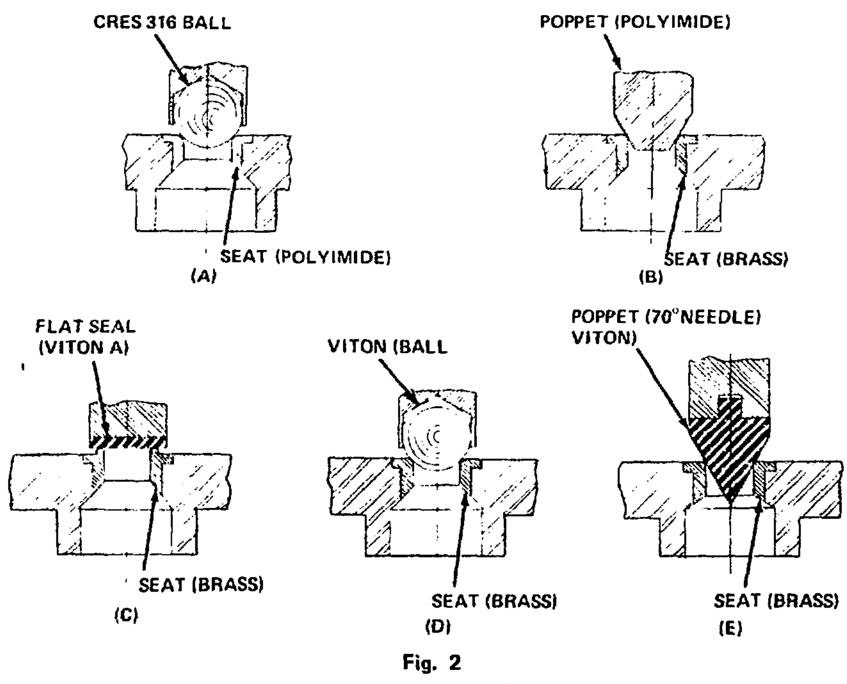

Fig. 2

provided successful modulation and repeatability over the entire throughput range. This design is now incorporated in the valve for further testing.

Test Program and Results

The test program is being conducted at PPPL. The primary objectives of this program utilizing the three engineering model valves are to

- Characterize baseline performances of the valve
- Evaluate performance variability
- Obtain reliability data relative to temperature exposure and life cycling.

The basic test setup is shown in Fig. 3. Throughput rates vs applied crystal voltages are determined from the pressure-time trace of the pulse into a 700-liter vacuum tank.

Testing has been performed with valves close-coupled to the vacuum tank to obtain baseline data, and also with simulated feed system line lengths of 100 cm, 200 cm, 300 cm and 400 cm to evaluate dynamic effects and lag time of the pulsed feed. Helium gas has been used as the test medium, but the complete test program will include characterizations with argon, deuterium and hydrogen gases in order to provide an adequate data base to extrapolate to *tritium gas.*

Preliminary testing of the valves indicated that the internal leakage requirement of 1×10^{-8} scc/sec with gaseous helium at one atmosphere pressure could not be met, which required that design modifications be made to the original sealing configuration. The evolution of the seal design has been described under the Valve Design section of this paper.

Throughput Modulation and Repeatability

A second problem area noted in the preliminary testing was throughput modulation and repeatability. Low level modulation and repeatability were not achievable until the conical Viton poppet shown in Fig. 2E was tested. Data showing throughput rate vs applied crystal voltage for this sealing configuration is shown in Fig. 4. The results show that the throughput can be modulated from a maximum instantaneous level of 490 Tl/sec at an applied voltage of 225 volts, to a minimum level of 12 Tl/sec at 140 volts. This range adequately covers the design requirement for a maximum throughput of 410 Tl/sec with the capability to modulate down to 50 Tl/sec. Good repeatability has been obtained over the modulation range as demonstrated in Fig. 4. It is planned to continue further characterization of this sealing configuration during the test program.

A pertinent concern relative to the use of cantilevered piezoelectric crystals is the repeatability of the crystal as a singular component, and variations in the deflection vs applied voltage characteristics for each individual crystal. Initial testing under this program with applied voltages up to 300 volts has indicated that the crystals will take a permanent set at high voltages and show large variations in valve repeatability. Because of this fact, a maximum limit of 225 volts has been established for the cantilevered crystals.

To further minimize the effects of individual crystal variations, it is planned to test an alternate configured valve that will utilize a single circular crystal to provide poppet deflection. This testing will be accomplished as part of the current test program. Further testing will also be performed at the Grumman Bethpage facility to fully characterize the cantilevered crystals as individual components.

Feed System Line Lengths

Preliminary tests were also performed with simulated feed system line lengths of 100, 200, 300, and 400 cm. The test tubing had an ID of approximately 1 cm. Results indicate that delta lag times considering both initial flow and time to 90% maximum throughput were in the order of 5 ms for the 100-cm tube length, 10 ms for the 200-cm tube length, 13 ms for the 300-cm tube length and 18 ms for the 400-cm tube length, when compared to the close-coupled valve. Further testing to ascertain repeatability of this data will continue.

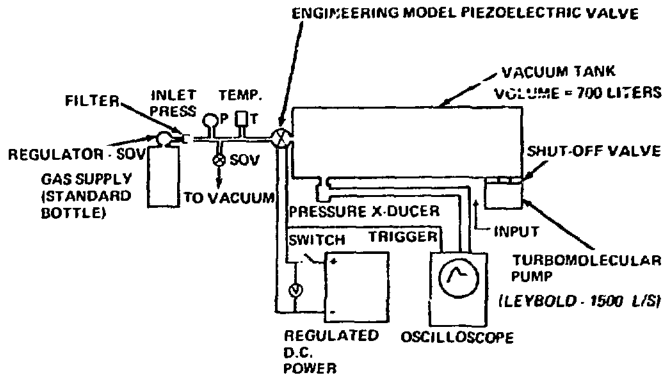

Fig. 3

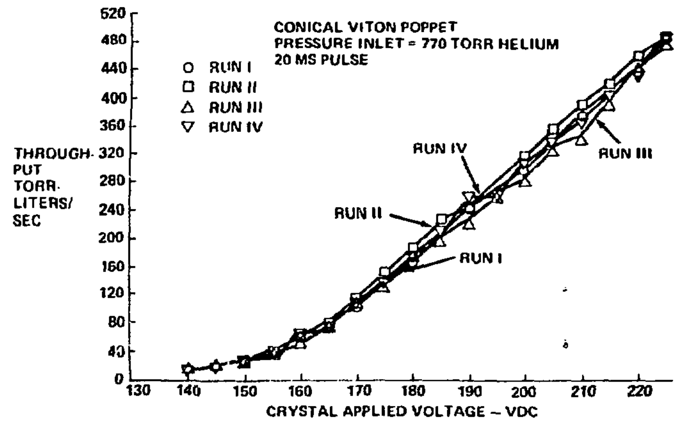

Fig. 4

Conclusions

From the testing accomplished to date preliminary conclusions indicate that:

- A tritium injection valve utilizing the principle of a piezoelectric crystal to control actuation and throughput modulation is a feasible concept
- A maximum instantaneous throughput of 410 Tl/sec with the capability to modulate down to 50 Tl/sec is achievable. Good repeatability has been demonstrated over this range with limited data. However, further testing is still required.
- Leakage rates in the range of 10^{-7} scc/sec with helium at 1 atmosphere pressure differential can be achieved
- Valve response times of 5 ms are achievable
- Evaluation of an alternate valve configuration utilizing a single circular piezoelectric crystal for poppet actuation will be made, for the purpose of minimizing effects of individual crystal variation and repeatability.