# Fluid Flow Characterization of Piezoelectric Gas Valves


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## Abstract

Piezoelectric gas valves are a major source of fueling for the Pegasus Toroidal Experiment. Piezoelectric crystals are electromechanical interaction materials, which contract or expand when electrical force is applied. Piezoelectric valves operate on a simple concept. When voltage is applied to the crystal, the crystal contracts and opens the valve inlet allowing the gas to pass. Characterization of these specific gas valves involves testing and calibration to obtain gas valve properties such as flow rate which are typically 100Torr*L/sec. Accurate flow characterization of these piezoelectric gas valves will assist experimentalists on the Pegasus Toroidal Experiment to understand how to better fuel their plasmas.


## I. Introduction

The Pegasus Team relies on piezoelectric gas valves for fueling their plasmas. An advantage of using piezoelectric gas valves over other fueling concepts such as pellet injectors is that piezoelectric gas valves operate on a simpler technology. In addition to simpler technology, piezoelectric have a high response time. A valve is mechanical device used to regulate or control the flow of a fluid or gas by closing, opening, or obstructing passageways. Piezoelectric gas valves are electromechanical valves, which have a piezoelectric crystal in them. The piezoelectric effect governs how the crystal in the gas valve behaves. When a electrical force is applied, such as a voltage the crystals contracts opens the inlet valve.

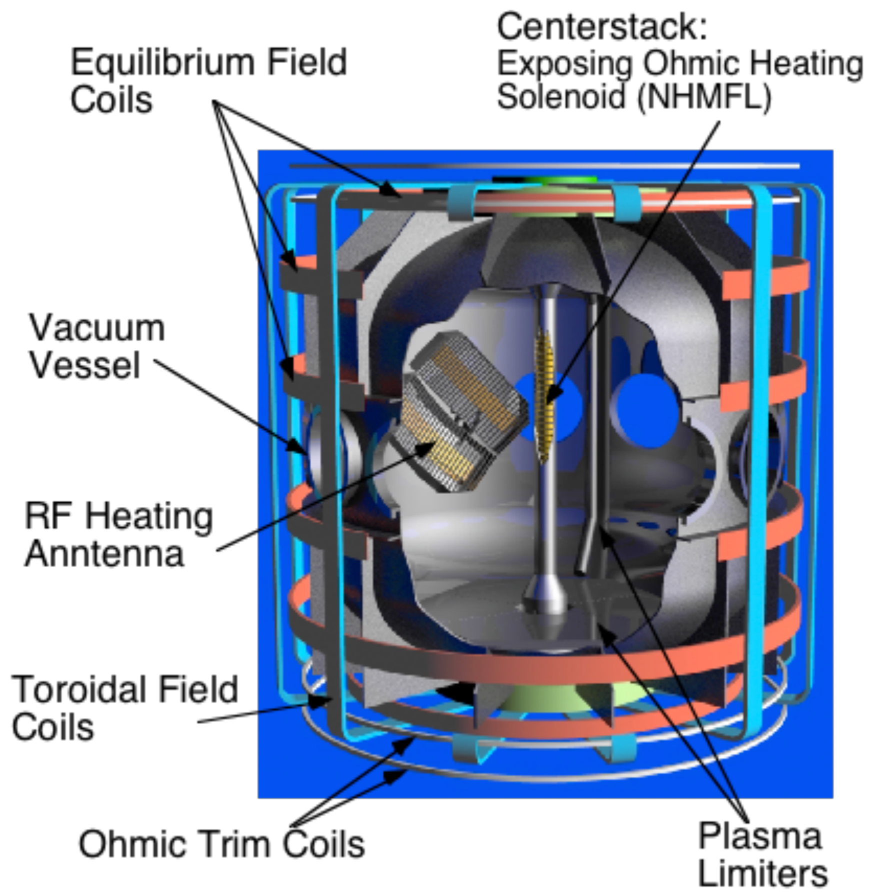



Figure 1. The Pegasus Toroidal Experiment is an extremely low aspect ratio spherical torus device located at the University of Wisconsin-Madison. We use magnetic fields to create a donut-shaped trap in which we create plasmas for study. (A magnetic trap is required because the extreme temperatures of a plasma will melt any physical container, destroying the plasma in the process.) The Pegasus research team is comprised of a small number of staff scientists, graduate students, and undergraduates. Students have been actively involved in the design, construction, and operation of Pegasus since its inception.

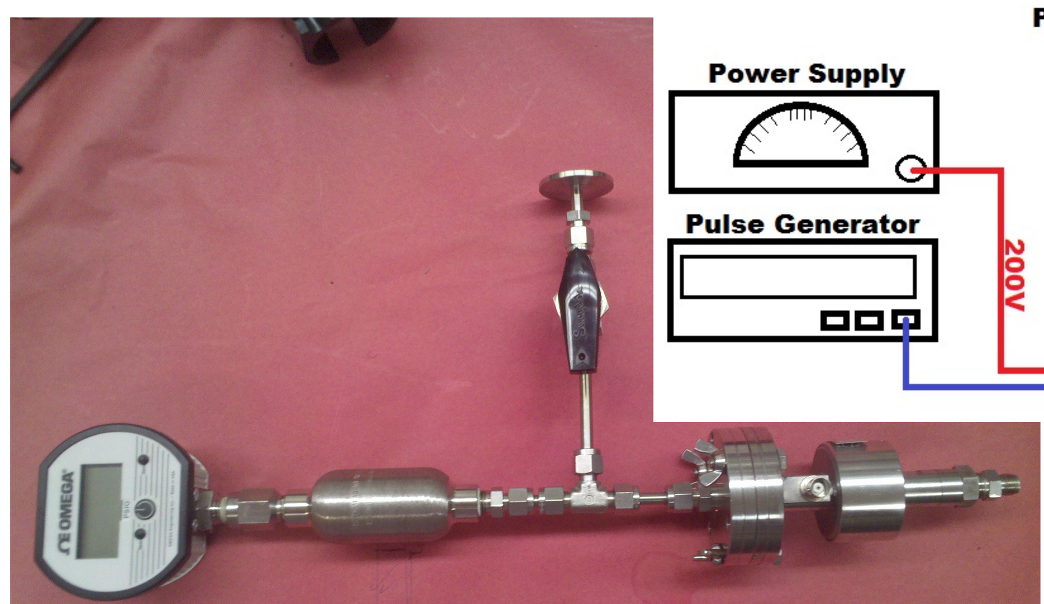


Figure 3. The testing apparatus used to measure flow rate for the piezoelectric valves. Components from left to right: 0 to 15 psi pressure transducer, 0.05 liter volume, ball valve, gas valve adaptor, PV-SS.

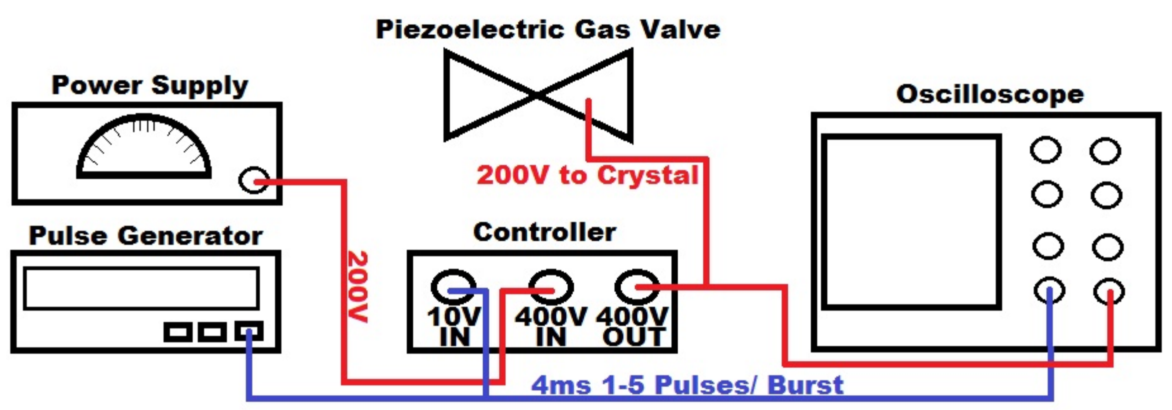



Figure 2. The electronic equipment used to send pulse signals to piezoelectric gas valves. The oscilloscope provides a visual reference to ensure voltage and signal was being applied. The controller is a device to simulate the controller on Pegasus. The pulse generator supplied the 4ms 1-5 pulses per burst, and the power supply was the 200V used to actuate the crystal.

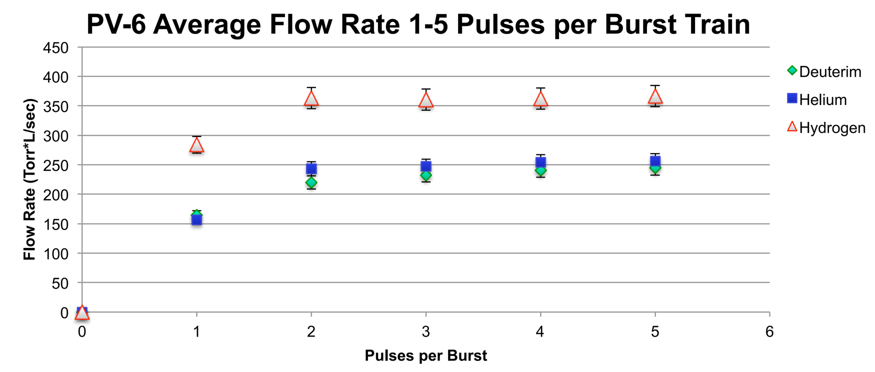
## II. Methods

The experiment is designed to calculate the flow rate of the fluid entering the vacuum cylinder from individual piezoelectric gas valves. The process in which each valve will be tested begins with the valve being tested and tuned on a leak testing stand to ensure that there is no gas leakage from the high pressure side to the low pressure side. Once the valves have been leak tested they are placed on the testing apparatus.

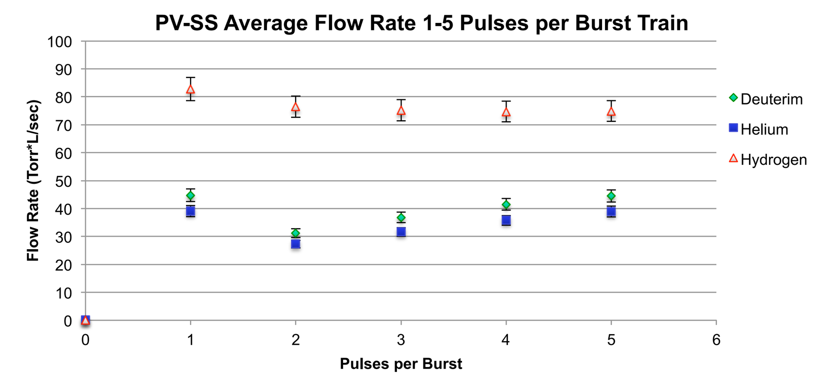
The testing apparatus is: a pressure transducer that measures absolute pressure, a vacuum vessel, a piezoelectric gas valve, and a vacuum pump. After the vacuum vessel gas is evacuated to the lowest pressure capable by the pump (0.80psia), a valve from the vessel to the pump is closed. The piezoelectric valves are operated at a function width of 4 milliseconds with a 50% duty cycle and have burst of 1, 2, 3, 4, and 5 pulses. The individual burst test are repeated for 50 shots. The tests are performed in a train or continuous form and the change in pressure from the previous to current pressure are measured for the pressure change.

## III. Results

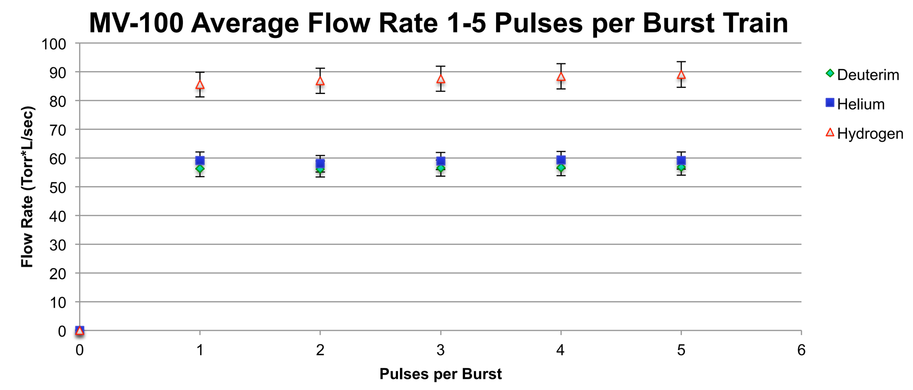
Each gas valve operates in the isentropic flow regime with isentropic relations. Due to the testing apparatus, measuring fluid properties is limited to pressure and flow rate. Using the ideal gas law $\rho_e = \frac{P_e}{R_* T}$ the density in the vacuum vessel can be calculated, where $P_e$ is the exit pressure, $R_*$ is the specific gas constant for the fluid, and $T$ is the temperature. After calculating the exit density the mass flow rate $m_e = \dot{\rho}_e V_e A_e$ is calculated, $V_e$ is exit velocity, and $A_e$ is the cross sectional area of the exit. Solving for exit velocity in the mass flow rate equation $V_e = \frac{\dot{m}_e}{\rho_e A_e}$ the theoretical exit velocity of the gas valve can be calculated. From the theoretical exit velocity the Mach number $M = \frac{V_e}{c}$ can be predicted where $c$ is the speed of sound in the gas. To calculate the experimental flow rate use $\dot{F} = V \ A_e \Delta P$ where $\Delta P$ is the change in initial pressure and final pressure for a single burst, and $\dot{F}$ is the flow rate at the exit location. Altering the flow rate equation to solve for velocity $V_e = \frac{\dot{F}}{A_e \Delta P}$ gives the experimental exit velocity for an individual burst.



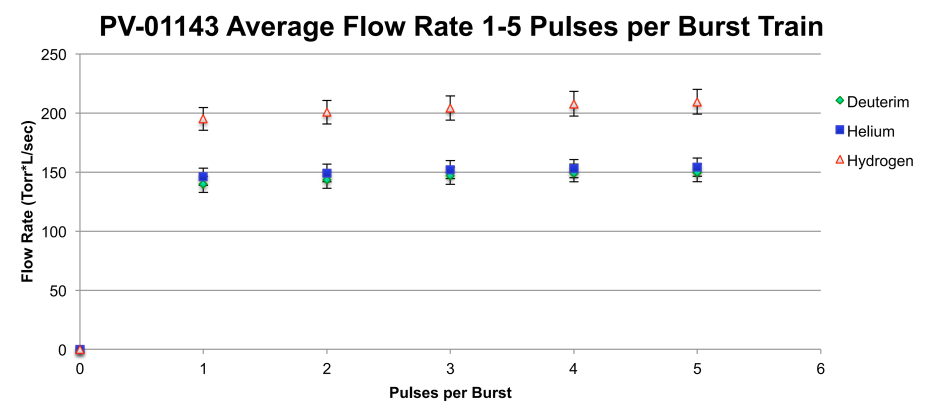

PV-6 is a standard modified PV-10 for Pegasus. The PV-6 has a constant inlet and outlet area of 3.694e-7m$^2$ with a length of 0.056m.




PV-SS is cone shaped, with an inlet area of 4.56e-7m$^2$ and a outlet area of 6.207e-5m$^2$ . The cone has a 4.5° half angle and a length of 0.052m.




MV-100 is a commercial piezoelectric gas valve. The MV-100 has an inlet area of 8.107e-7m$^2$ and a 90° outlet 0.009m from the inlet with an area of 1.979e-7m$^2$




PV-01143 is a non-modified PV-10, that has a constant inlet and outlet area of 2.027e-7m$^2$ with a length of 0.005m.

**Piezoelectric Gas Valves Average Flow Rates**

| Valve | Helium | Hydrogen | Deuterium |
|---|---|---|---|
| MV-100 | 58.95 Torr*L/sec | 87 Torr*L/sec | 59.45 Torr*L/sec |
| PV-6 | 254 Torr*L/sec | 360 Torr*L/sec | 240.833 Torr*L/sec |
| PV-SS | 31.63 Torr*L/sec | 74.73 Torr*L/sec | 41.50 Torr*L/sec |
| PV-01143 | 150 Torr*L/sec | 200 Torr*L/sec | 150 Torr*L/sec |

## IV. Conclusions

After analysis of the results, a better understanding of the piezoelectric gas valves flow rates will allow for better fueling for the Pegasus Team. The MV-100 gas valves operated at the manufacture's specifications. The non-modified PV-10 the PV-01143 operated about the manufacture's flow rate. While the manufacture operated the PV-01143 at 100V and 15psi, the Pegasus team operated the valve at 200V and 50psi. The PV-6 operated well about the average flow rate for a standard PV-10, due to the increase in inlet and outlet area. The PV-SS is the gas valve with the lowest flow rate. The PV-SS is designed as a supersonic cone, with a small inlet area and larger exit area.

## V. References


[1] V. Soukhanovskii and H. Kuge, "Supersonic Gas Injector for Fueling and Diagnostic Applications on the National Spherical Torus Experiment," Review of Scientific Instruments, 2004.

[2] Benedict, Robert. Fundamentals of Gas Dynamics. Wiley, 1983.

[3] B. Pegourie, E. Tsitrone, R. Dejarnac, J. Bucalossi, G. Martin, and J. Gunn, "Supersonic Gas Injection on Tore Supra," *Journal of Nuclear Materials*, 2003.

[4] C. E. Hawk, W. C. Baker, and Hasting-Raydist A Teledyne Company, "Measuring Small Gas Flows into Vacuum Systems,"*Journal of Vacuum Science and Technology*, 1969.

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