# Normally-Closed, Leak-Tight Piezoelectric Microvalve with Ultra-High Pressure Upstream Flow Control for Integrated Micropropulsion

***Category: 6. Actuators***


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**Novelty:** A 'helium leak detector scale' leak rate of $9x10^{-5}$ sccm has been obtained at an upstream pressure of 800 psi. A fast (< 10 ms) microvalve operation has been successfully demonstrated at the pressures in the range of 0~1000 psi.


**Background:** Integrated micropropulsion concept........ Current up-to-date photo or figure of integrated micropropulsion system available by Juergen ➔ (Fig 1)
Integrated micropropulsion systems for the attitude control of microspacecraft require precisely controlled, extremely small propellant flow from a highly pressurized propellant tank. A microvalve for micropropulsion applications require fast actuation with a very low leak rate at an extremely high propellant pressure as described in Table 1 [1]. Previously reported microvalves do not meet the requirements for pressure range or leak rate [2-5]. Recently reported electrostatic microvalves operate at 10 atm [6], which still falls short of pressure range. Thermally actuated microvalves usually have slow response time [7], unacceptable for micropropulsion applications. Significant efforts are required for the development of microvalves to meet the micropropulsion requirements. The author's group recently presented a proof-of-concept design of a piezoelectric valve, without sufficient leak-tests addressing pressure tolerance [8]. In this abstract, we present a fully characterized leak-tight piezoelectric microvalve to control flow under extremely high upstream pressures for micropropulsion.

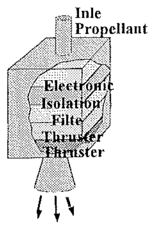
**Implementation**: The microvalve consists of a seat plate, a boss plate and an actuator (Fig. 2 (a)). All silicon valve components are metal-to-metal compression bonded in a leak-proof, high-pressure tolerance metal packaging (Fig. 2 (b)). A series of narrow rings on the seat plate reduces potential leakage due to scratches over a seat ring (Fig. 3). The boss plate has the center plate with a 2 μm thick PECVD oxide layer, providing an initial seating pressure attributable to tensile stress in the silicon tether extended by the seat. A piezoelectric stack (block pressure 50 MPa, Curie temp. 235 °C) with mechanically separated active zones is bonded on top of the boss plate. Application of a potential (~50V) to the stack causes the active zones to vertically expand by 5 μm, lifting the boss center plate (bonded to the inactive zone in the center part of the stack) away from the seat plate. This action creates a channel between the two openings, allowing for the passage of fluids. ......... Juergen: Integration aspects and methods with VLM or so...

Fabricated microvalves have been characterized at upstream inlet pressures of up to 1000 psi. Testing beyond 1000 psi has not been performed due to safety factor of current test facilities. The leak test for a microvalve reveals extremely low, 'helium leak detector level' leak rates (<$9x10^{-5}$ sccm) at the pressures in the range of 150~800 psig (Fig. 4). The leak is undetectable at the pressures lower than 150 psi. Fig. 6 presents nitrogen flow rates of the actuated microvalve at variable applied potentials and pressures. Since a microvalve for micropropulsion needs to control a very small amount of flow, the microvalve can be operated at 10V (See Fig. 5.), with which the power consumption is 0.5 W at 100 Hz continuous actuation. Fig. 6 shows the flow rates of a microvalve actuated with pulse width modulation at variable operating frequencies (10Hz-1kHz) and pressures. Fig. 7 presents a frequency dependent flow rates. Sinusoidal input of +/- 10 V is applied to the piezoelectric actuator of the microvalve. Future works will be the flow tests of microvalves integrated with microthruster components at < 3000 psi in extreme environments.

**References**


1 Mueller, *35th AIAA/ASME/SAE/ASEE Joint Propulsion Conf. and Exibit*, AIAA 99-2725. 2. Mueller, *et al.*, *Proceedings of SPIE* 4558 (2001), p. 57. 3. Vandelli, *et al.*, *J.MEMS*, 7 (1998) p.395. 4. Xie, *et al.*, *IEEE MEMS* '01, p.539. 5. Huff, *et al*, *Solid State Sensor and Actuator Workshop* '92, p.194. 6. Yang, *et al.*, *Solid State Sensor and Actuator Workshop* '02, p.19. 7. Barth, *Transducers* '95, p. 276. 8. Yang, *et al.*, *ASME IMECE* '02 to be presented.

***Word Count: 569***




| Leak Rate | < 0.005 sccm/He |
|---|---|
| Actuation Speed | < 10 ms |
| Inlet Pressure (gas) | 0 – 3000 psi |
| Power Consumption | < 1 W |
| Weight | < 10 gm |
| Temperature | -50 °C to 150 °C |

Table 1 Microvalve requirements for NASA's miniature spacecraft propulsion

Fig. 1 Integrated micropropulsion concept.

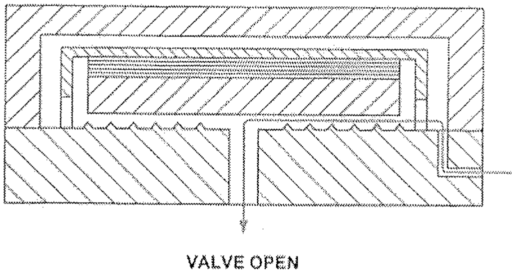



Fig. 2 Normally-closed, leak-tight piezoelectric microvalve. (a) Concept schematic (b) High-pressure packaged microvalve.

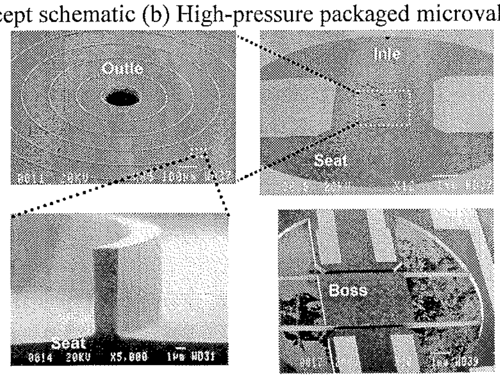



Fig. 3 SEM photographs of the seat plate and the boss plate. Narrow seat rings increase the seating pressure, contributing to reduce leakage. Top surfaces of rings are covered by 0.5 μm thick thermal oxide. This hard seating configuration has been proven to work at ultra-high pressure.

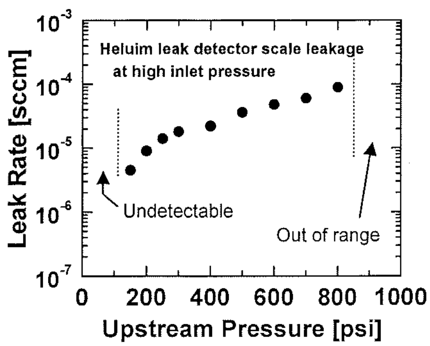



Fig. 4 Internal leak rates of a normally-closed (non-actuated) valve are <9x10$^{-5}$ sccm at upstream inlet pressure of 800 psig. The leak is undetectable at < 150 psi.

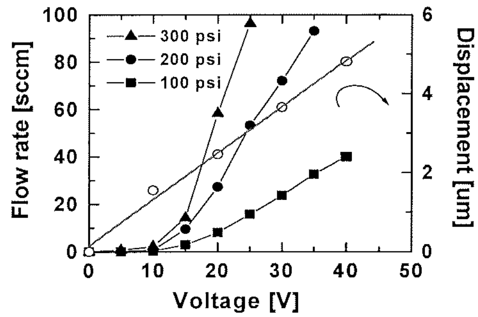



Fig. 5 Flow rates of an actuated microvalve. The piezoelectric operation of the microvalve has been successfully demonstrated at the pressures in the range of 0~1000 psi. Flow rates beyond 300 psi are out of range of the flow meter used in the tests.

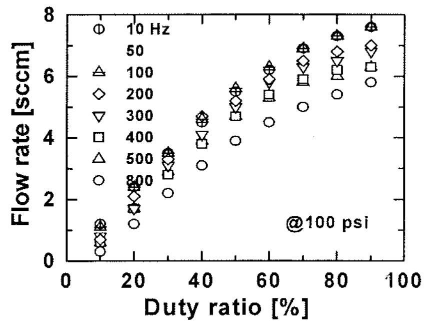



Fig. 6 Flow rates of a microvalve actuated with pulse width modulation at several operating frequencies and variable pressures. (Applied 10V pulse)

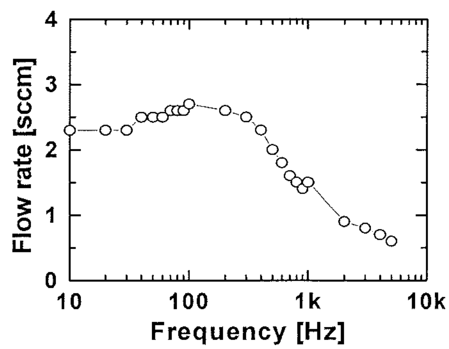



Fig. 7 Frequency dependant flow rates of a microvalve actuated at 200 psi, demonstrating a fast (<10ms) valve operation. (Applied +/- 10 V sine wave)