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Development of MEMS-Based Piezoelectric Microvalve Technologies

Eui-Hyeok Yang*, **, Choonsup Lee and Jay M. K0hodadadi[1]

Jet Propulsion Laboratory, California Institute of Technology 4800 Oak Grove Drive, Pasadena, CA 91109, USA
[1]Mechanical Engineering Department, Auburn University 201 Ross Hall, Auburn, AL 36849-5341, USA

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In this paper, we describe an overview of our development of piezoelectric microvalves for microspacecraft applications, and a summary of the results of the computational modeling of the microvalves. The microvalves have been designed, fabricated and characterized for the proportional flow control of propellant for spacecraft micropropulsion. The microvalve consists of a custom-designed piezoelectric stack actuator bonded onto silicon valve components with the entire assembly contained within a metal housing. The valve seat configuration includes narrow-edge seating rings and tensile-stressed silicon tethers that enable the normally closed and leak-tight operation. A concentric series of narrow rings simulates a “knife-edge” seal by greatly reducing the valve contact area, thereby increasing the seating pressure and consequently reducing leakage. Leak testing of the microvalve, conducted using a Helium leak detector, showed a leak rate of approximately 5×10^{-3} sccm at 800 psi for the gas-compatible version and a leak rate of approximately 3×10^{-6} scc/s at 50 psi for the liquid-compatible version, respectively. Dynamic microvalve operations (switching rates of up to 1 kHz) have also been successfully demonstrated. The measured static flow rate for the gas-compatible microvalve under an applied potential of 10 V was 52 sccm at an inlet pressure of 300 psi. The measured forward flow rate for deionized (DI) water for the liquid-compatible microvalve is approximately 64 mg/min at an inlet pressure of 20 psi and an applied voltage of 50 V. The measured power consumption, in the fully open state, was 3 mW at an applied potential of 30 V. The measured dynamic power consumption was 180 mW for 100 Hz continuous operation at 100 psi. A computational fluid dynamics (CFD) package was used for the 3-dimensional modeling of the flow in the liquid microvalve. The liquid experienced the greatest pressure loss as it moved over the rings in the gap between the seat and boss plates. A correlation for the pressure drop coefficient as a function of the gap spacing between the seat and boss plate was obtained. As for the gaseous microvalve, a 1-dimensional compressible flow model was developed, accounting for the excessive frictional effects of the seat rings. The variations of compressible flow quantities due to friction were studied, showing the drastic increase in density and static pressure in contrast to a rather small increase in the Mach number. Also of great importance, the total pressure drop was shown to be significant across the seat rings.

*Corresponding author, e-mail address: eyang@stevens.edu
**Dr. Eui-Hyeok Yang has transferred to Stevens Institute of Technology, Castle Point on Hudson, Hoboken, NJ 07030, USA