Development of Long-Lifetime Pulsed Gas Valves for Pulsed Electric Thrusters

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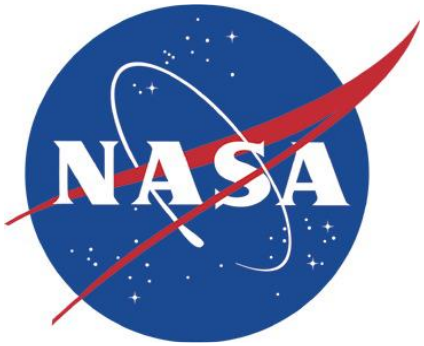

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Introduction

- Long lifetime needed for gas-fed pulsed electric thrusters
  - Gas-Fed Pulsed Plasma Thrusters
  - Inductive Pulsed Plasma Thrusters
- Require 10^{10} – 10^{11} pulses for missions of interests
- Only allow propellant to flow for operation (Open and Close quickly)
  - Gas injected too early diffuses away
  - Gas injected late will miss the electrical pulse
- Two designs explored for fulfilling the pulsed valve requirements

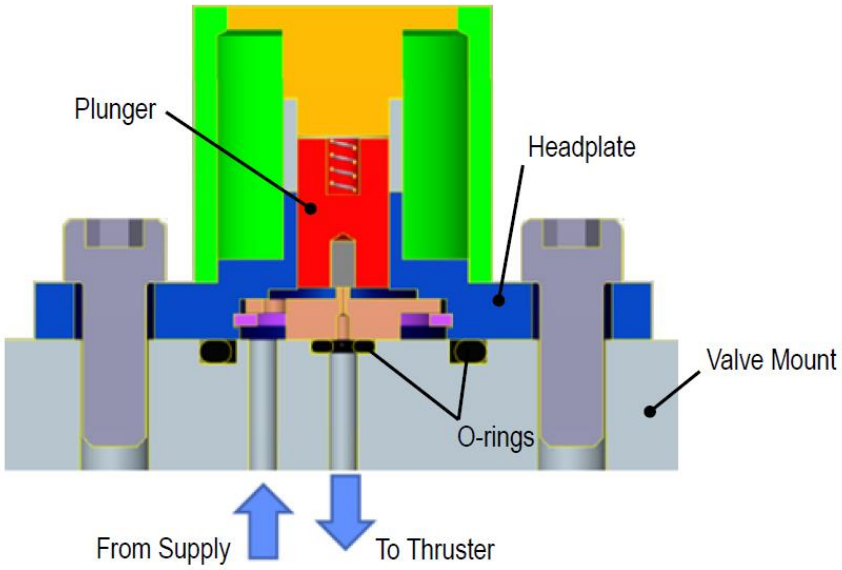
Requirements

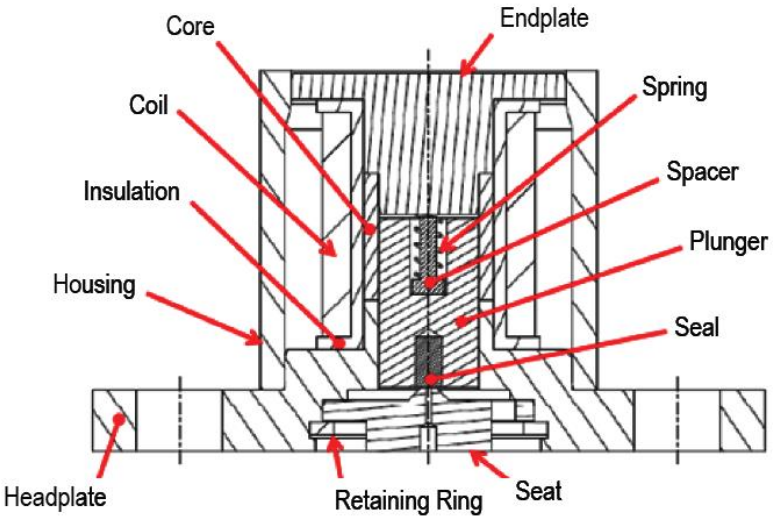
Parameter	Requirement
flow rate	$\geq$ 164 sccm (10 scim) GAr @ 276 kpa (40 psia) inlet pressure, 0 kPa (0 psia) outlet pressure and 21 °C (70°F)
opening & closing response	$\leq$ 1 ms (goal) at 103-690 kPa (15-100 psid) and 21-149°C (70-300°F)
internal leakage	$\leq 1 \times 10^{-3}$ sccs GHe at 103-690 kPa (15-100 psid) and 21-149°C (70-300°F)
cycle life	$> 10^9$ cycles
operating temperature	up to 149 °C (300°F)

- Even 10^9 cycles is well above anything demonstrated

Solenoid Actuated Valve

- Electromagnetically-actuated solenoid valve
- Normally-closed valve design with Viton valve seat
- Flange-mount for easy integration into test apparatus





Solenoid Actuated Valve – Baseline Results

- Tests performed with GHe

temperature (°F)	pressure (psig)	internal leakage (sccs)	pull-in voltage (VDC)	drop-out voltage (VDC)	flow rate (scim)	opening response time (ms)	opening response time (ms)
68	20	1×10^{-4}	15.1	1.6	15.9	1.7	8.7
	40	1×10^{-4}	15.0	1.5	22.8	1.8	8.8
	140	6×10^{0}	16.0	1.4	38.1	2.0	8.9
305	20	1×10^{-4}	11.2	1.8	12.5	1.0	6.4
	40	8×10^{-5}	11.7	1.6	20.6	1.0	6.4
	140	1×10^{-3}	12.4	1.8	36.9	1.0	6.5

- Valve elastomeric seat swelled with increasing T, reducing stroke
  - Lower pull-in voltage
  - Lower flow rate
- Response time slower than requirement of < 1 ms

Solenoid Actuated Valve – Long Duration

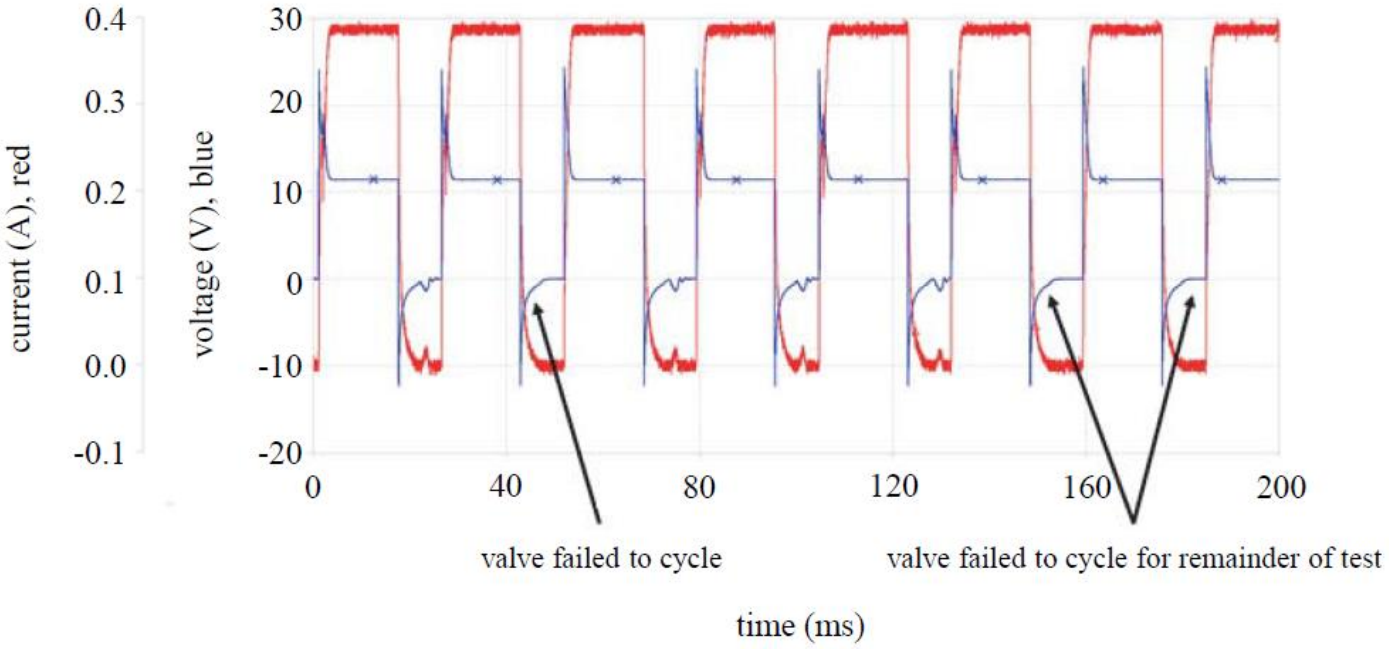
- Inlet of 40 psig, 300 deg F

	number of cycles							
test parameter	**0**	**1,000**	**5,000**	**10,000**	**50,000**	**150,000**	**250,000**	**1,000,000**
internal leakage (sccs)	8×10^{-5}	2×10^{-5}	2.4×10^{-4}	1.4×10^{-6}	1.0×10^{-6}	4×10^{-5}	2×10^{-5}	1.2×10^{-6}
pull in voltage (VDC)	11.7	11.4	11.1	11.1	11.2	11.9	12.6	11.4
drop-out voltage (VDC)	1.6	2.1	2.1	2.0	2.0	1.6	1.6	1.7
open response time (ms)	1.0	1.0	1.0		0.9	1.0		0.9
close response time (ms)	6.4	6.3	6.1		4.1	4.8		4.4

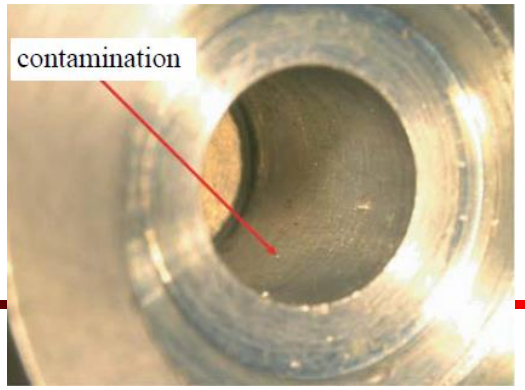
YELLOW cell color: data questionable. RED cell color: data not read properly/no data.

- Achieved one million cycles before valve failed to cycle

Solenoid Actuated Valve – Long Duration

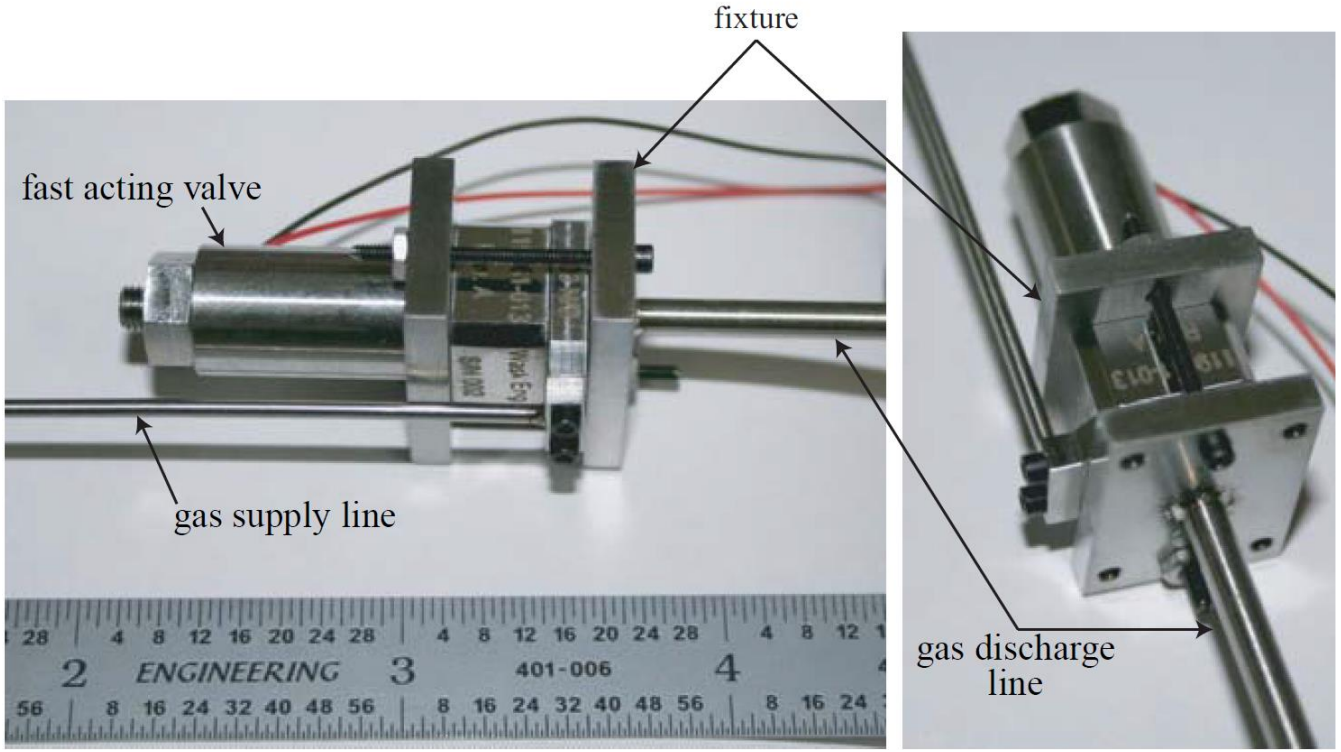


- Wear on plunger sliding surface and in plunger bore / sliding contact



Piezo Crystal Actuated Valve

- Piezoelectrically-actuated valve
- Normally-closed valve design with very short stroke
- Spherical pintle and mating surface seal



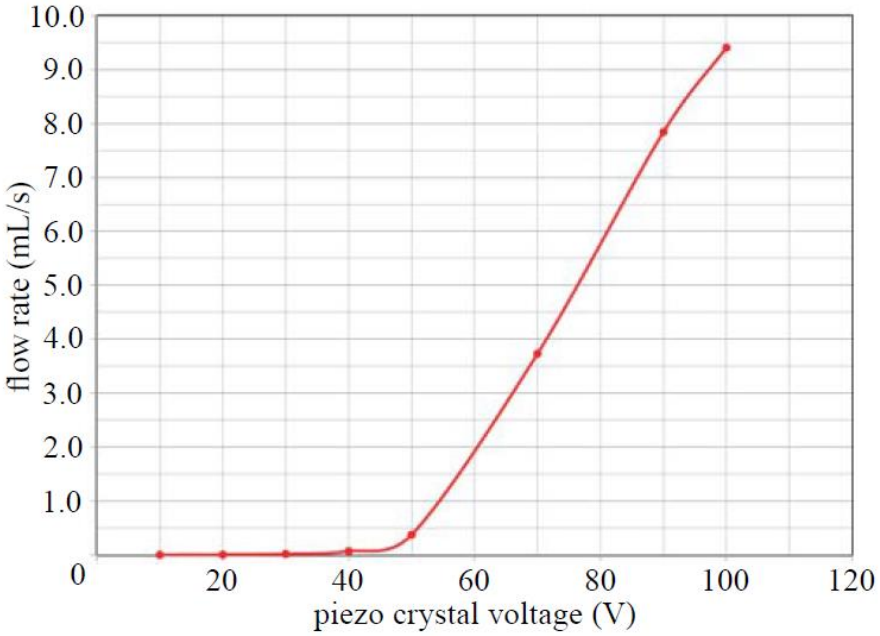
Piezo Crystal Actuated Valve - Specifications

- Flow rate controlled by inlet pressure and/or applied voltage level

Parameter	Value	Units
voltage range	0 to 100	V
temperature range	-40 to 150	°C
nominal travel	11±2	μm
blocking force	825	N
stiffness	75	N/μm
capacitance	1.7±0.34	μF
resonant frequency	85	kHz
average power (1 kHz, 3%)	5.1	mW
est. insulated heating rate	2.58	°R/s

Piezo Crystal Actuated Valve - Results

- Flow rate calibration (N_2 at 40 psia and 70 deg F)

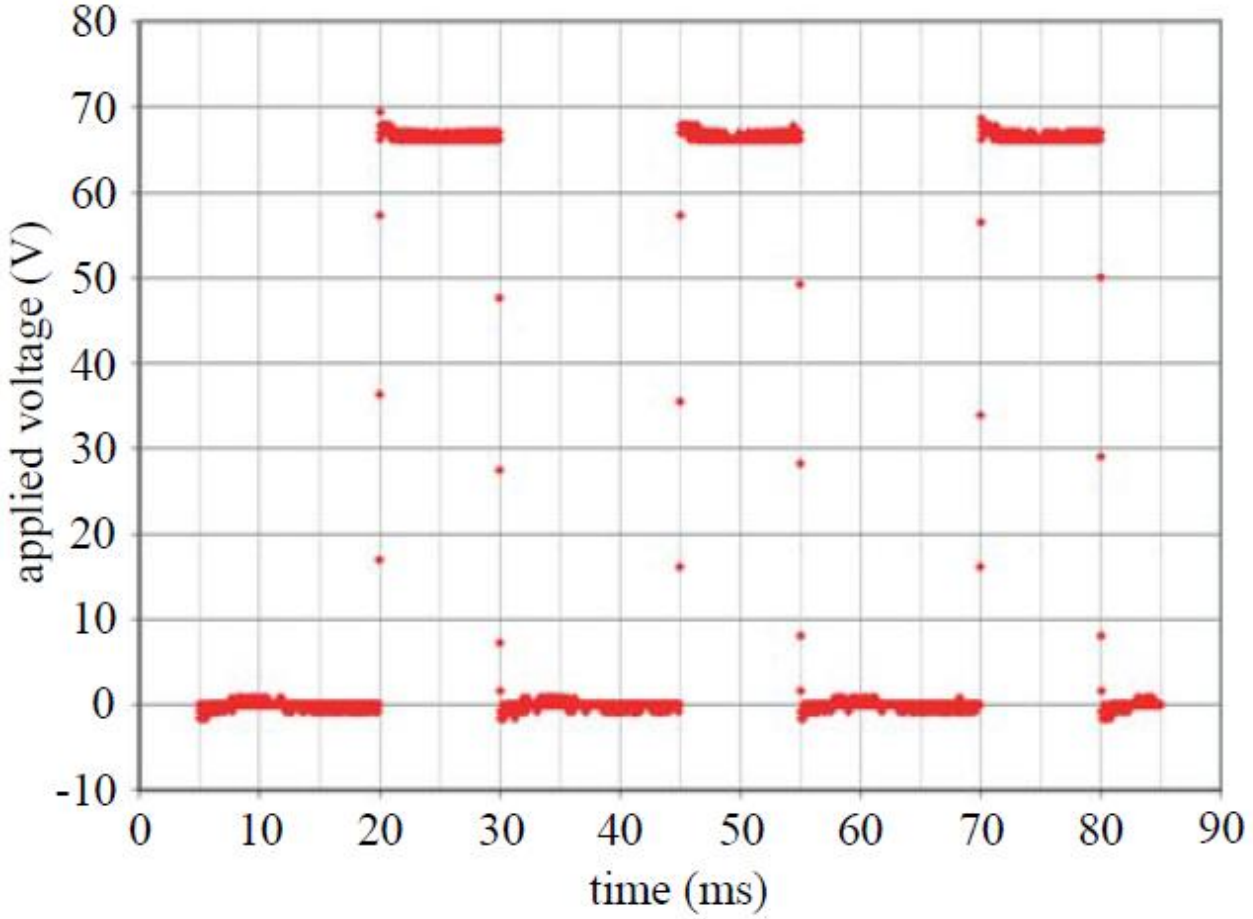


- Leak rate quantification (initial quantification meets goal of < 10^{-3} sccs)

Initial Burette He Volume (mL)	Final Burette He Volume (mL)	He Leakage Volume (mL)	Test Duration (sec)	Leak Rate (cc/sec)
7.45	8.40	0.95	1,125	8.44×10^{-4}

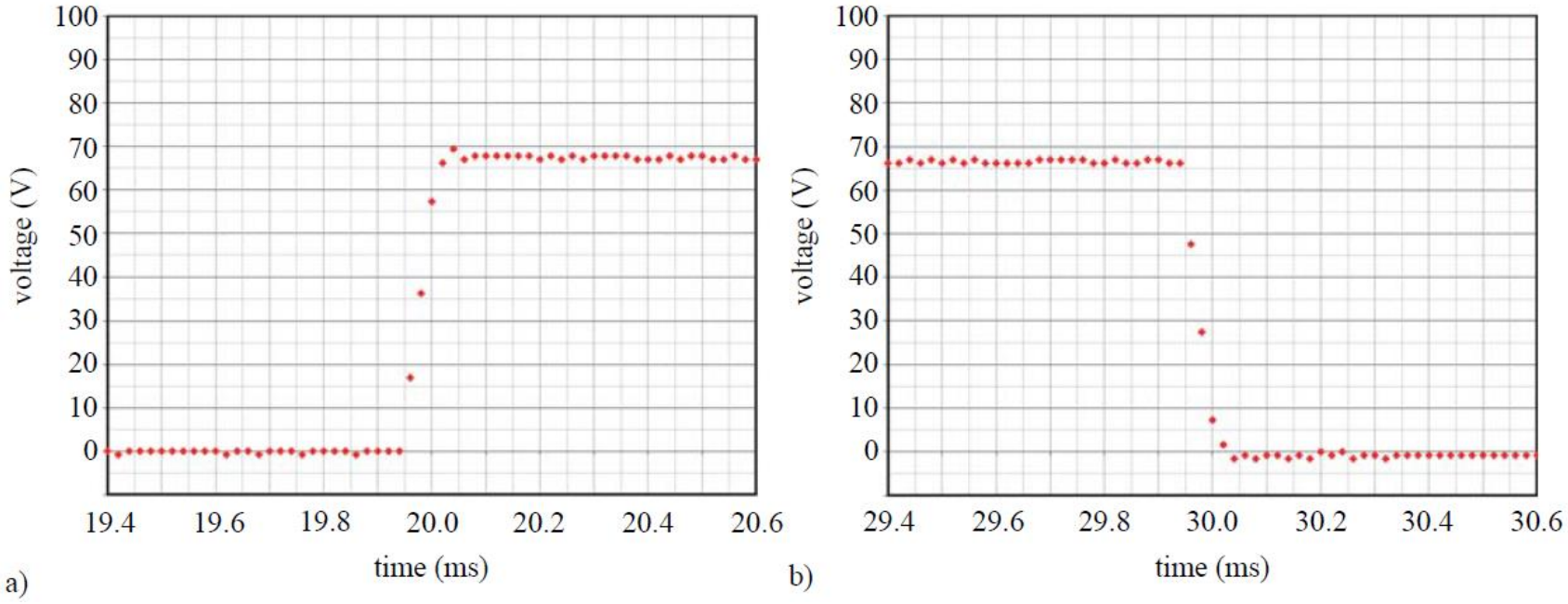
Piezo Crystal Actuated Valve - Results

- Input voltage at 40 Hz repetition rate, 10 ms pulse width



Piezo Crystal Actuated Valve - Results

- Voltage rise and fall times



- Meets goal of < 1 ms opening & closing time

Piezo Crystal Actuated Valve - Summary

- Benchtop Test Summary

Parameter	Value	Units
flow rates (at 40 psia and 70°F)	0-10	mL/s
pulse width	2 ms to inf	–
opening time	100	μs
closing time	100	μs
throttling	0-100% of flow	–
internal leakage	0	sccm of He
valve seat leakage	8.44×10^{-4}	sccs of He
operating temperature range	-40* to 300	°F
current/voltage/power	5.1** / 100 / 0.51	mA / V / W
displacement	0.00032	inches
force margin	429%	–
proof factor	1.5*MEOP	–
factor of safety (ultimate / yield)	>2.5 / >1.4	–
mass	22.5	g

* Limited by piezo crystal, which has been operated to temperatures well below this value.

** Current requirement a function of operating frequency (1 kHz assumed here).

Conclusions

- Two types of valves fabricated and tested

- Both …
  - Demonstrated the ability to throttle flow rate
  - Achieved leakage rates $< 10^{-3}$ sccs Ghe at beginning of life

- Piezo Valve Demonstrated…
  - Range of flow rates up to ~10 mL/s
  - Opening and closing in 100 µs or less
  - Low power draw

- Solenoid Valve Demonstrated…
  - Range of flow rates up to ~10 mL/s
  - Opening and closing times that did not meet the requirement
  - One million cycles before valve failure (binding from excessive wear on valve plunger sliding surface) … Valve SEAT still sealed at this point in test

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