High Speed Puff Valve Techniques: Piezoelectric and Electromagnetic

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Abstract

This research investigates various methods of fast moving valve operation, namely piezoelectric and electromagnetic methods. Due to certain insufficiencies in existing methods, we designed our own electromagnetic "moving disk" valve capable of both static and pulsing operation, and after testing a prototype of this design, we found it to be capable of 70 μs rise times with even faster times possible with further optimization. This technology is mainly applicable in fusion research, but further applications may present themselves in the future.

Previous Valve Designs

- Piezoelectricity: property of a material that expands/contracts when a voltage is placed across it.
- Used in fast puff valves with piezoelectric disk actuators (Figure 1a).
  - Piezoelectric ceramic laminated to the bottom of a stainless steel disk attached to a metal plunger.
  - Voltage across the two faces $\Longrightarrow$ Piezoceramic contracts radially causing steel disk to cup upward.
  - Plunger is lifted slightly upward to open the orifice and allow gas to flow through the valve.
- Advantages: Quick pulsing operation as well as longer static operation.
- Disadvantages: Voltage limit exists.
  - Larger actuators = large distances at slower frequencies.
  - Smaller actuators = faster frequencies over small distances.
  - Increasing voltage past a certain threshold (usually 1000 V) depolarizes piezoceramic.
- Collaborated with UW research group looking into a piezoelectric valve design (Figure 1b).
  - **PUT IN FINAL EXPERIMENTAL RESULTS!!!**
  - Rise time was slower than we had hoped, necessary to pursue different methods.

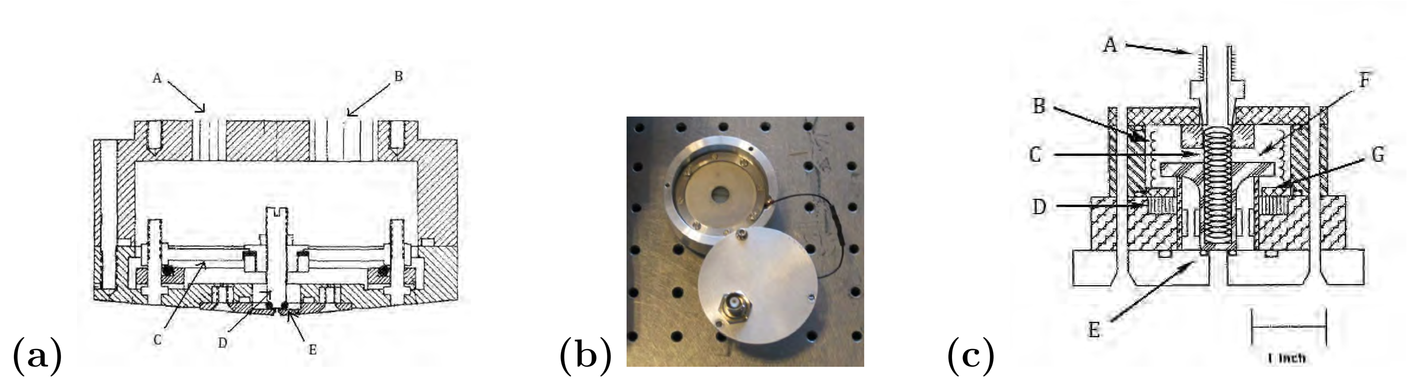

FIGURE 1: **(a)** Diagram of piezoelectric valve designed by D. Proch and T. Trickl[1] (A=Gas inlet, B=BNC connection, C=Piezoelectric disk actuator, D=Orifice plunger, E=O-ring and orifice), **(b)** disassembled piezoelectric valve used for experimenting, and **(c)** diagram of electromagnetic valve designed by Kriesel, Prohaska, and Fisher (1991).[3] (A=Gas inlet, B=Hammer return spring, C=Poppet return spring, D=Solenoid coil, E=O-ring and orifice, F=Nylon poppet, G=Aluminum hammer ring)

- Other designs utilize more common electromagnetic principles rather than piezoelectricity to operate.
- Design put forth by J. Kriesel, R. Prohaska, and A. Fisher from UC Irvine (Figure 1c).
  - Electric current is quickly introduced into a solenoid beneath an aluminum ring.
  - Change in magnetic flux through the aluminum ring induces a current within it (Faraday's Law).
  - Moving charge is repelled upward by the magnetic field of the solenoid.
  - Ring collides with a nylon poppet and effectively opens the valve.
  - Induced current wears off $\Longrightarrow$ Springs on ring and poppet return valve back to closed position.
- Advantages: Operation only limited by strength of materials and available power source.
  - Theoretically, electromagnetic valve can operate much faster than the piezoelectric design.
- Disadvantages: Quick pulsing operation only.
  - Inherently incapable of longer static operation, necessary for our purposes.

Proposed Valve Design

- Developed an electromagnetic valve capable of static operation (Figure 2).

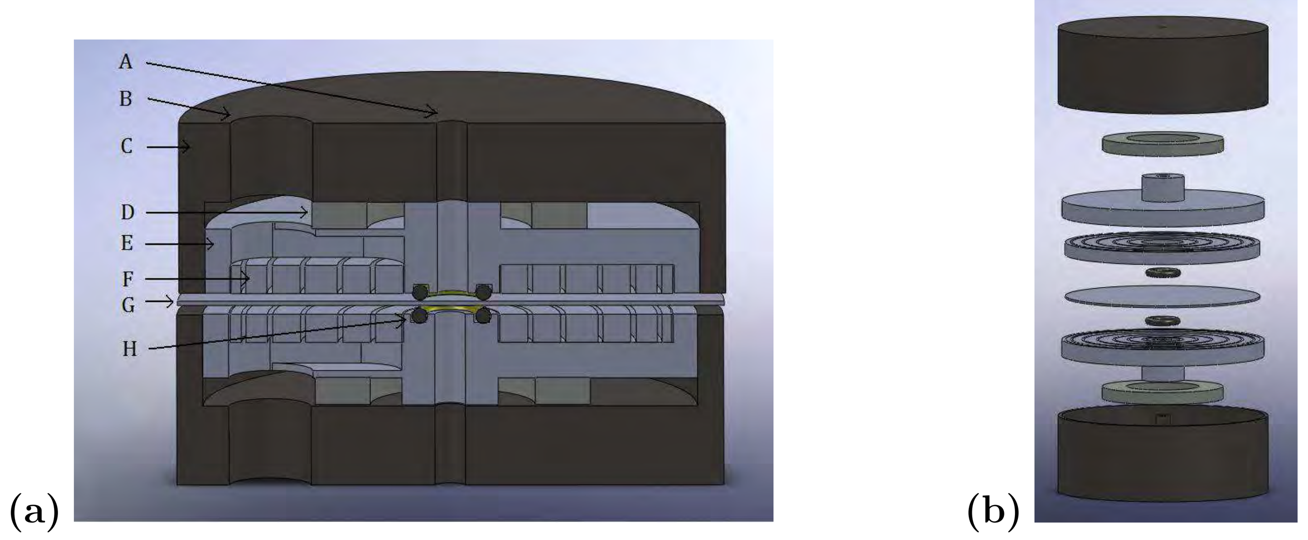

FIGURE 2: Solidworks model of proposed valve, **(a)** Cross sectional view (A=Gas inlet, B=BNC inlet, C=Upper iron casing, D=Permanent cylindrical magnet, E=Aluminum solenoid plate, F=5-turn pancake solenoid, G=Aluminum/Steel moving disk, H=Buna-N O-ring) and **(b)** disassembled view.

- Like UC Irvine group, design moves metal disk to effectively open the valve.
  - Rather than using aluminum hammer ring, ferromagnetic steel disk used within our design.
  - Magnetic field of neodymium permanent magnet rerouted through iron casing around the solenoid.
- Steel disk repelled into open position by introducing current through the bottom solenoid.
  - Held open by the upper permanent magnet.
- Disk repelled into closed position by introducing current through the top solenoid.
  - Held closed by the lower permanent magnet.
- Therefore capable of pulsing operation as well as static operation.
- Rise times only restricted by the strength of materials and available power source.
- Theoretically, design can produce 100 μs rise times using approximately 7 kA at 1.5 kV.
  - Well within the capabilities of power sources available at Eagle Harbor Technologies.
- Another aspect to be further investigated: Composition of the moving disk.
  - Must contain enough steel to be attracted by the permanent magnet.
  - Including aluminum reduces the weight and requires less power to repel it.
  - Experimenting with steel and aluminum disks as well as laminated disks with both materials.

Experimental Set-up

- Placed fiber optic displacement sensor within the gas inlet of the valve to measure distance.
  - Instrument emits light from the end of its fiber bundles and reflects back off moving disk.
  - Analog hardware transmits voltage proportional to intensities of the emitted and reflected light.
  - Amount of light received decreases with distance $\Longrightarrow$ Intensity directly correlated to distance travelled by disk.
  - Output read on oscilloscope and rise times are derived from the signal
  - Accurate to within a tenth of a micrometer using a 200 kHz sampling frequency.
- Powered the valve using four 32 μF capacitors in parallel and fast switch IGBT boards.
  - IGBT switches capable of fully opening in 40 ns

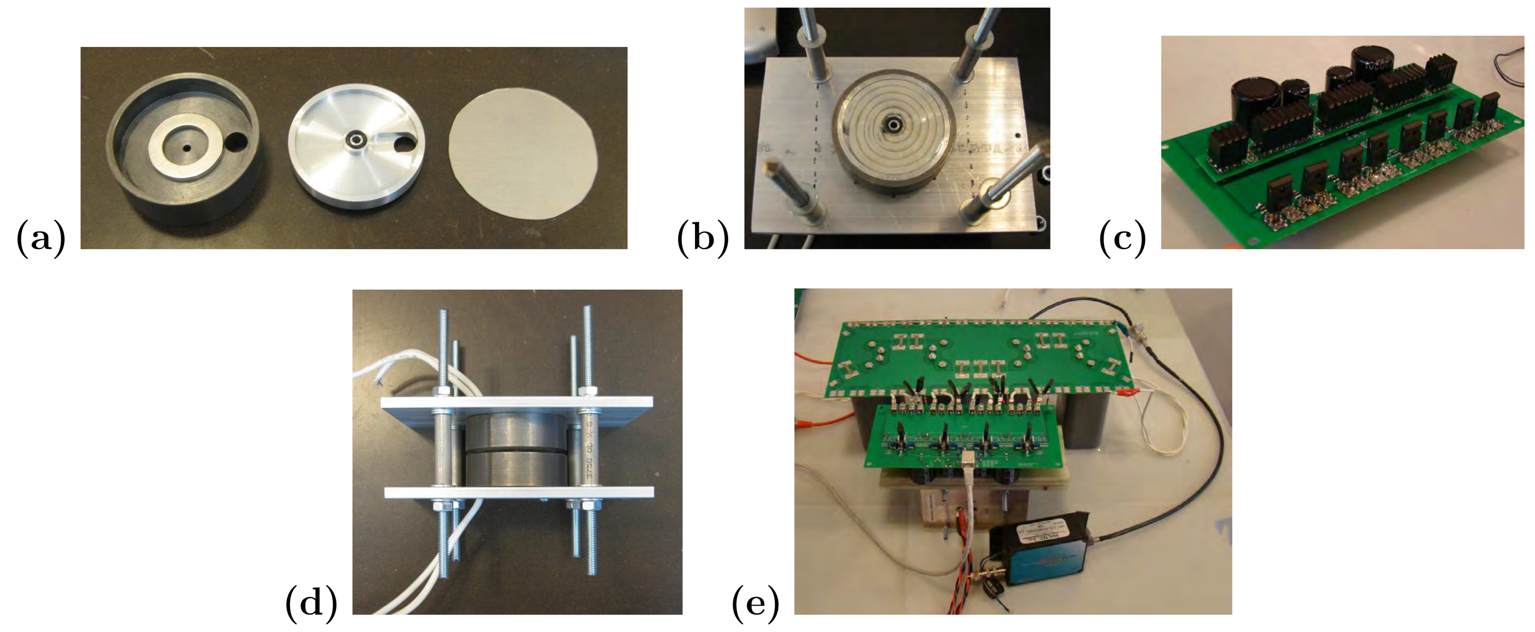

FIGURE 3: **(a)** Individual valve components, **(b)** assembled configuration of valve upper half, **(c)** High Current Adapter on IGBT board, **(d)** fully assembled moving disk valve, and **(e)** complete experimental set-up.

Results and Conclusion

- Using 1000 V over the capacitors generates a peak current of **12 kA**.
  - Equivalent to a magnetic field of **1.08 T** and a force of **905 N**.
- Produces 70 μs rise time over 1 mm gap based on output of fiber optic sensor.
  - Much faster than a greater percentage of valves available today.

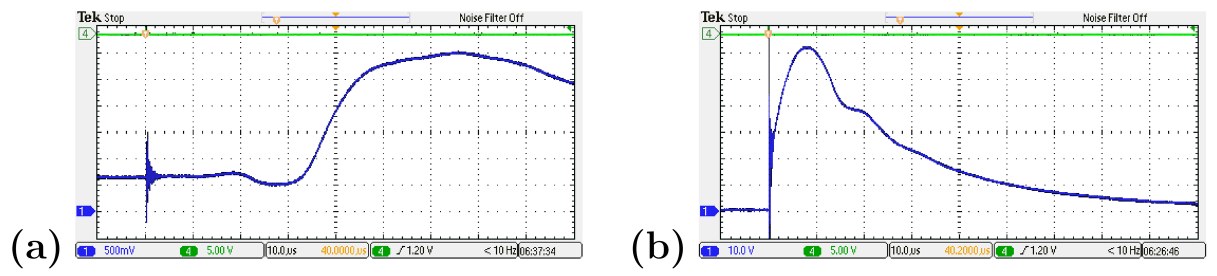

FIGURE 4: **(a)** Output of fiber optic displacement sensor using 1000 V pulse suggesting a 70 μs rise time, and **(b)** voltage signal over a 5 mΩ resistor suggesting 12 kA of current.

- Multiple aspects to further investigate:
  - Composition of moving disks (steel and aluminum laminates).
  - Reducing inductance of solenoids within the valve.
  - Testing in a vacuum chamber, reducing air resistance.
  - Using different locations for gas inlet to aid rise times.

Acknowledgements

A special thanks to the Washington NASA Space Grant Consortium for making this internship possible, everyone at Eagle Harbor Technologies for their help and guidance, MEB Manufacturing for machining the necessary parts, and Aaron Hossack for his aid in testing his piezoelectric valve.

References

[1] Proch, D., and Trickl, T. (1988). *A high-intensity multi-purpose piezoelectric pulsed molecular beam source.* Rev. Sci. Instrum. **60** (4), 713-716.

[2] Schießer, A., and Schäfer, R. (2009). *Versatile piezoelectric pulsed molecular beam source for gaseous compounds and organic molecules with femtomole accuracy for UHV and surface science applications.* Rev. Sci. Instrum. **80**.

[3] Physik Instrumente (PI) L.P. (2010). *Tutorial: Piezoelectrics in nanopositioning, designing with piezoelectric actuators.* Retrieved from http://www.physikinstrumente.com/en/products/piezo_ tutorial.php.

[4] Kriesel, J., Prohaska, R., and Fisher, A. (1991). *Simple, fast, puff valve.* Rev. Sci. Instrum. **62** (10), 2372-2374.

[5] Milanese, M.M., Pouzo, J.O., Cortazar, O.D., and Moroso, R.L. (2006). *Fast valve and nozzle for gas-puff operation of plasma focus.* Rev. Sci. Instrum. **77**.

[6] Gentry, W.R., and Giese, C.F. (1978). *Ten-microsecond pulsed molecular beam source and a fast ionization detector.* Rev. Sci. Instrum. **49** (5), 595-600.

[7] Philtec, Inc. (2010). *Operating instructions for fiber optic displacement sensors with analog output, Type D.* Retrieved from http://www.philtec.com/newanalogD.pdf.

[8] Parker Hannifan Corp. (2011). *Parker o-ring handbook.* Retrieved from http://www.parker.com/literature/ORD%205700%20Parker_O-Ring_Handbook.pdf.

[9] K & J Magnetics, Inc. (2011). *Technical specifications of RX4C2 cylindrical magnet.* Retrieved from http://www.kjmagnetics.com/proddetail.asp?prod=RX4C2.