Development of a Prototype High Speed Piezoelectric Valve for LTX

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Background

The Lithium Tokamak experiment is an important experiment to see how a liquid lithium coating on the plasma facing wall of a tokamak can affect plasma confinement.

It is advantageous to have the hydrogen fuel injected on the inner or high field side of the Tokamak, for more efficient utilization of the gas.

To achieve this the injector valve must be very small as it needs to fit between the inner vacuum wall and the plasma. Piezoelectric valves are a natural choice for this, however commercial valves are too large. Thus it has been necessary to begin development of a smaller valve capable of the same time response.

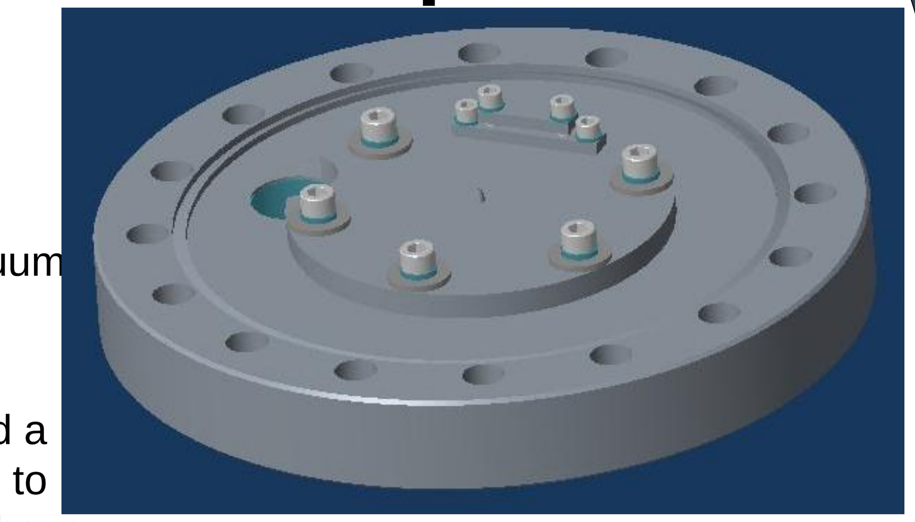
Deformation of piezoelectric crystals causes a charge to build up within them. If charge is induced via an external electric field the crystal will deform accordingly.

Project Goals/Objectives

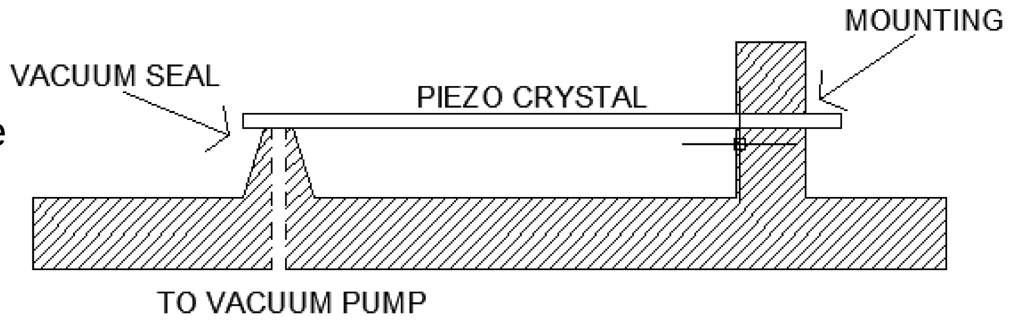
- To develop a prototype piezoelectric valve that is capable of being scaled down to the required size.
- To characterize the nature of the motion of the Crystal in the valve.
- To Determine the response time of the crystal and thus the shortest possible gas puff
- To Determine the reproducibility of the system to repeated use.

Experimental Setup

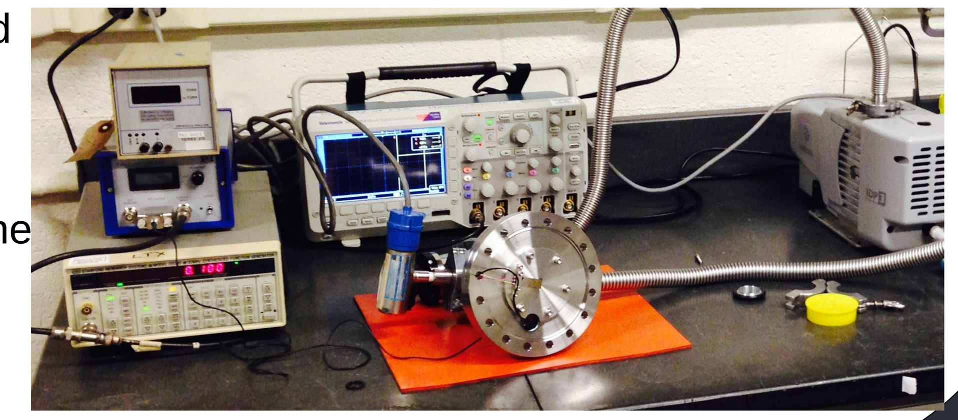
- A blank six inch conflat flange was chosen as the base plate.
- A hole was drilled through the center, a mini conflat was welded to the hole, and attached to a vacuum pump, leak checker and pressure gauge.
- A mounting plate with a nozzle and a a rear facing O-Ring was attached to the base with the nozzle directly above the vacuum hole.



- One end of the piezo was mounted, the other was laid on the nozzle to create the seal. Viton was attached to the crystal's ends for this purpose.

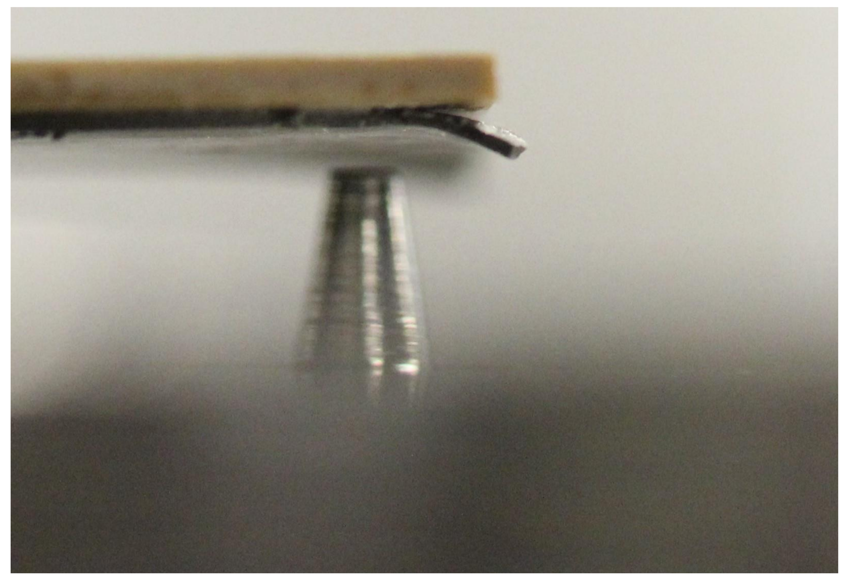


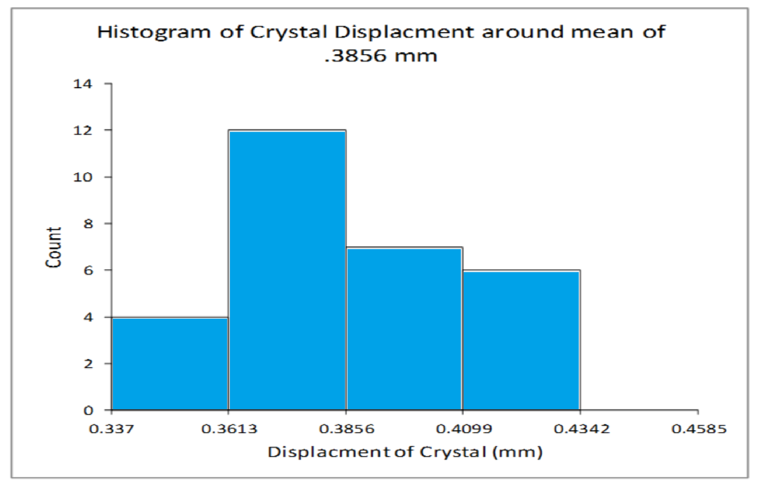
- The power supply was gated by a pulse generator. This was done in order to precisely control the length the voltage was applied to the crystal and thus the amount of time the valve was open.



Characterization of Crystal

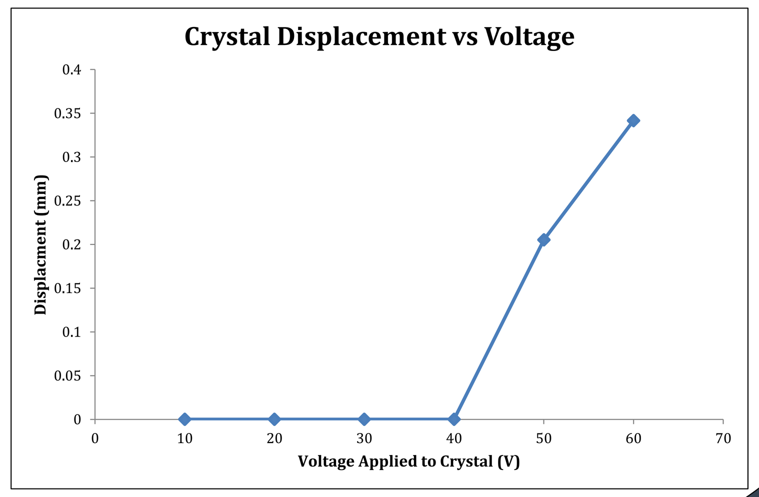
ImageJ applied an algorithm to pictures taken of the deformed crystal. The algorithm determined the length represented by a single pixel, using the nozzle as a known scale. The algorithm then measured the displacement of the crystal. Using an image of the closed valve, the program corrected for the position of the nozzle in the middle of the crystal.





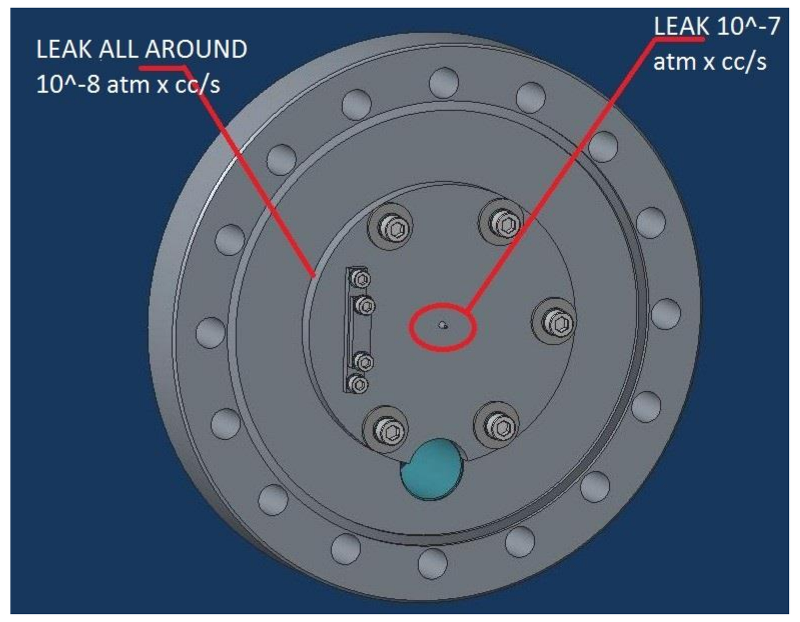
In order to test the algorithm and determine if the crystal opened the same amount each time, the valve was opened and closed 29 times. A picture was taken for each cycle. The histogram of the results are on the left. The distribution is tightly grouped which indicates that the algorithm works and the crystal will reproducibly open to the same amount.

Another quantity of interest was how the crystal opened as a function of applied voltage (electric field). The valve was photographed at six operating voltages as seen to the right. From the graph it is clear that the crystal will not open at voltages below 40V.



Leak Testing and Pressure Differential

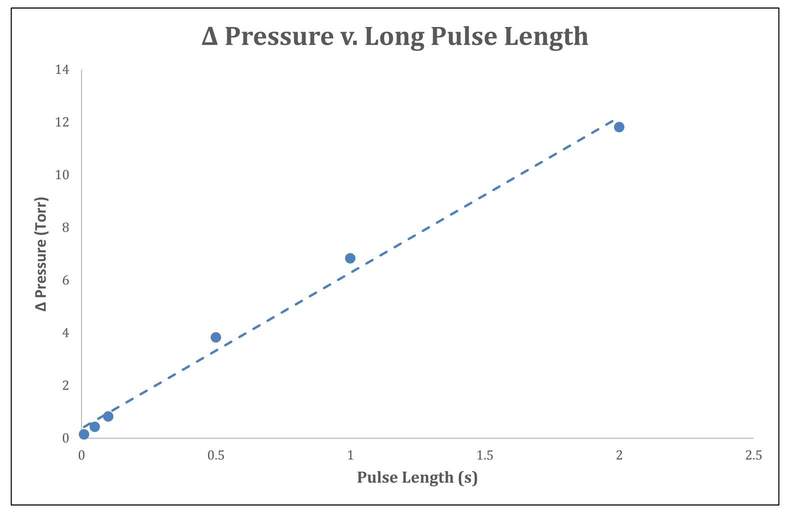
In order to be used as an effective gas valve the piezo crystal needed to maintain a good seal. To check the seal the Oerlikon leak checker was used to pump the system down to 1mTorr. The leak detector identified three leaks within the valve assembly. The first two occurred at the mini-conflat and along the edge of the mounting plate on the scale of 10^-8 atm x cc/s of helium. These were caused by assembly errors. There was a more serious leak around the seal on the scale of 10^-7 atm x cc/s.

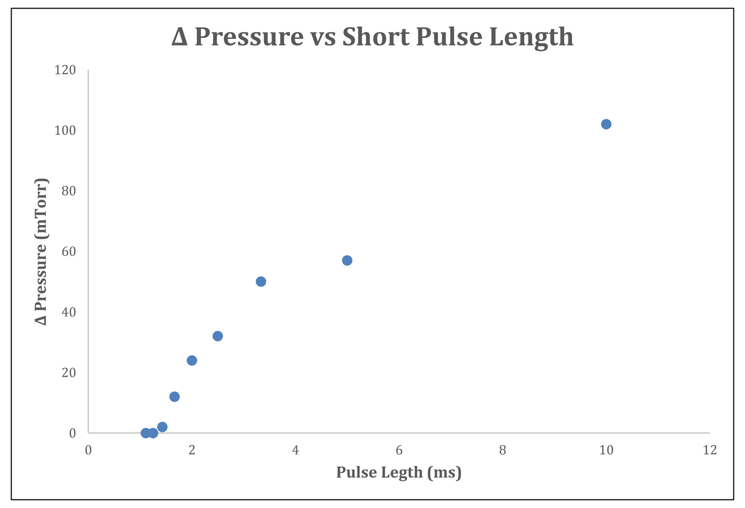


The "sealing force" of the crystal was found using the pressure differential. The vacuum applies no pressure so the atmosphere applies the only force equal to: $F = P\pi r^2 \approx 10^5\pi(.00025)^2 \approx .02N$ which is about 5% of the maximum load force of the crystal.

Time Response of Gas Valve

The shot length for LTX is around 30ms. So the gas valve needs to have a time response much shorter then that. To determine this the system was pumped down to vacuum and the valve was opened for specific lengths of time. The pressure before and after the puff was recorded. The results for the longer pulses is recorded on the right. It shows that the increase in pressure is linear in time for long puffs.





In the short pulse regime (to the left) the change in pressure goes roughly linear until the duration falls below 2ms at which point the change rapidly goes to zero. This is because the valve fails to open. The reason for this is most likely that the amount of electrical energy applied is insufficient to produce the impulse necessary to move the crystal any faster.

Summary and Conclusions

- The motion of the crystal is consistent over many runs and consistently opens when a pulse is applied.
- The crystal only begins to open in the range of 40V.
- There are several major leaks in the system that will need to be addressed in future tests.
- The pressure differential calculation indicates that the non-vac side of the system should be able to be pressurized to several atm.
- In the long pulse regime the pressure increases linearly with pulse length, as expected.
- In the short pulse regime it can be seen that the minimum pulse length that results in significant pressure increase is 2ms
- The reproducibility of the system is good and not a subject of concern.

Future Research

- Pressurize the non-vacuum side to 3-4 atm and observe impact
- Use a duel polarity power supply and vary the voltage from -30V to 30V instead of 0V to 60V to increase sealing force.
- Develop new smaller prototype.

Acknowledgements

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