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VALVES BASED ON AMPLIFIED PIEZOELECTRIC ACTUATORS

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Abstract

Amplified Piezo Actuators have been developed at CEDRAT TECHNOLOGIES for several years. Their well – known advantages (rapid response and precise positioning) have been used in valve designs to obtain both rapid or fine proportional valves.

A first gas valve is using a small amplified piezo actuator and is further driven with a switched amplifier to get a high frequency modulation. Frequency modulation higher than 400 Hz with a stroke of 100 µm have been measured. This properties can also be used for gasoline injectors.

A second gas valve is also using an amplified piezo actuator, a linear amplifier, and a servo controller to get an accurate proportional valve dedicated to precise gas flow control in the fields of instrumentation and space. A linear and stable flow control has been demonstrated. The low power consumption of the piezoelectric valve in the space applications is an additional advantage. A stable flow of dry Nitrogen ranging from 0.1 sccm to 200 sccm has been measured with a inlet pressure of 1 bar.

These valves have been designed with the help of several modelling tools : finite element procedure for the electro-mechanical part, the contact mechanics between the poppet and the seat, the computational fluid dynamics. The valves have been further measured by using several measuring equipment's, including a laser interferometer, a spectrum analyser to measure the gas flow stability, … With this design methodology, these valve can be redesigned to meet other requirements

1. Introduction

Piezovalves have been considered for their quick response in diesel injections system. However, the displacement produces by the actuator is too small, so that large flow under low inlet pressure cannot be mastered. One interesting alternative is to use mechanical amplified piezoeletric actuator [1] to circumvent the previous mentioned drawback.. This presentation deals with the design and test of two piezo – actuated valves aimed at performing several jobs.

2. Design consideration

The major consideration in a valve design is linked to the presence of the actuator in the pressure chamber. The valve design including the actuator in the pressure chamber are simple, but becomes heavy for large actuator and still remains dependant on the chemical compatibility between the piezoelectric layer insulation and the fluid.

The second important consideration relies on the poppet's geometry : a flat poppet is suitable for on / off operation, whilst a pin geometry is suitable for a proportional operation. In this case, the guiding and the centering of the pin poppet should be mastered.

3. Actuator inside the pressure chamber

A small tiny valve based on a APA100S actuator has been designed by using CAD software. this small valve is intended to simulate an music instrument. The piezo actuator APA100S (sroke of 100 µm) was driven by a switching amplifier SP75. Frequency modulation higher than 400 Hz with a stroke of 100 µm have been measured. The self – heating is negligible and, depending on the poppet geometry, the flow can be as high as 6 slm under a inlet pressure of 8 bars.

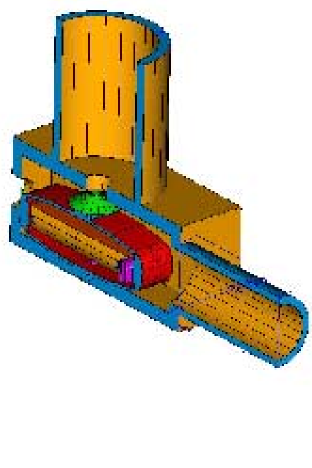


Figure 1 : CAD view of a tiny piezo valve.

4. Actuator outside the pressure chamber

The main design consideration is the pressure isolation between the actuator and the pressure chamber : this can be accomplished through dynamic O-rings, a diaphragm or a bellows. The latter solutions are preferable for clean operations such as those seek in space and semi-conductor industries.

Figure 2 : Photograph a second piezo actuated valve.

5. Design tools

Several design tools have been used to model the valve behaviour:

- finite element procedure to evaluate the guiding and isolation sub – system,
- finite element procedure (ATILA software) to evaluate the piezo electric actuator behaviour,
- computational fluid dynamic routines to evaluate the fluids behaviour and the resulting flow law [3]. An axisymmetric model using non compressible fluids has been set up : its validity can be considered satisfactorily under Mach 0.3.

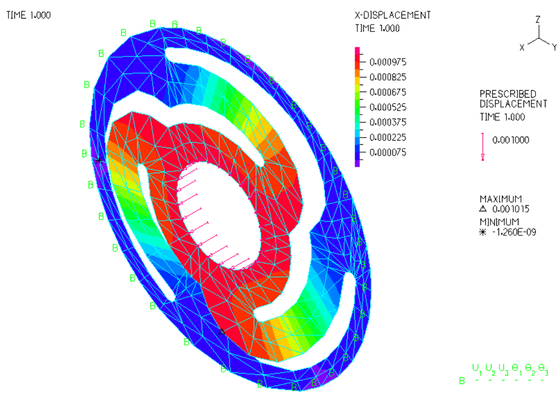


Figure 3 : Example of S-shaped spring that could be used as inner guiding spring.

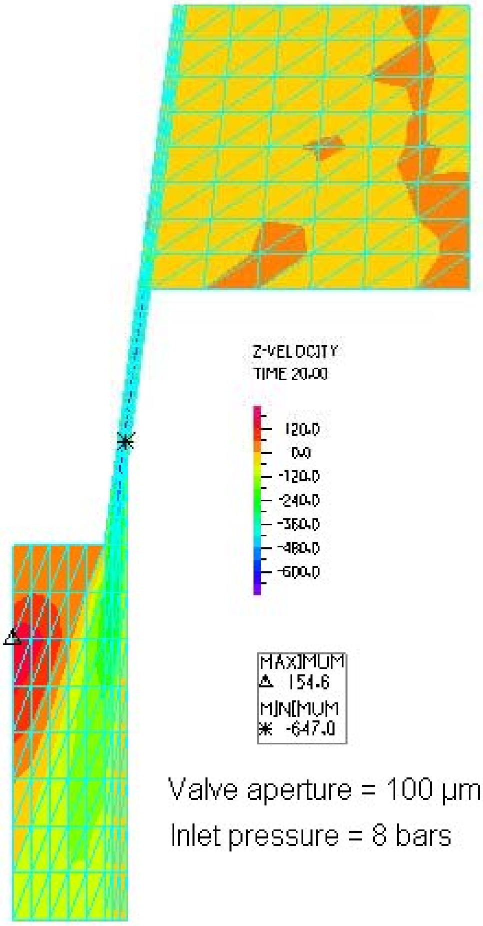


Figure 4 : Example of a CFD computation on a pin valve configuration

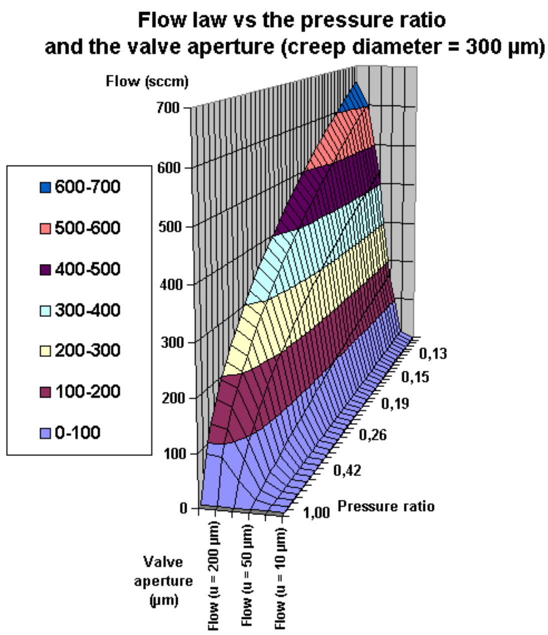


Figure 5 : Computed flow law as a function of the valve aperture and the inlet pressure.

For a throat diameter of 250 µm, the Reynolds number is expected to reach 20000, so that a transition between the laminar and the turbulent flow is likely to occur : this can possibly affect the proportional behaviour.

Regarding the pin valve, one key difficulty still remains the mastery of the pin excentration during the integration process. This aspect becomes critical in the case of reduced throat diameter. Because the seat is screwed, there are some possibilities of self – centering of the pin, depending on the radial stiffness of the guiding. A centering error of the pin is also likely to affect the flow law of the valve. These aspects would need a 3 dimensional CFD analysis.

6. Experimental results

The experimental behaviour has been assessed on a dedicated test bench at CEDRAT TECHNOLOGIES. It includes an upstream reservoir, a mechanical pressure regulator, a inlet pressure transducer, a outlet pressure transducer, a gas flowmeter.

The flow law under a constant upstream pressure was first assessed (Figure 6). Then, the flow law was measured for several upstream pressures. Whilst at low inlet pressure, the behaviour is linear, it saturates at higher inlet pressure because the gas reaches the sonic regime (Figure 7).

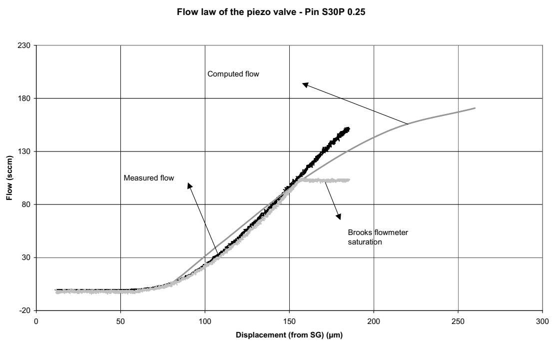


Figure 6 : Computed and measured flow law.

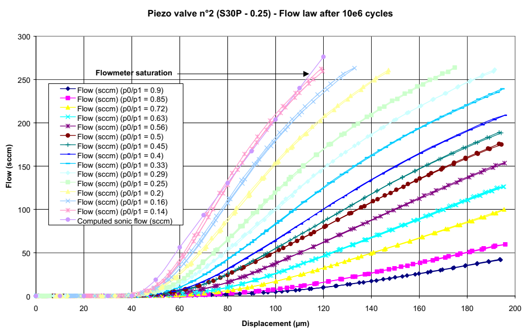


Figure 7 : Flow law of the valve.

In a second step, the valve behaviour was linearized by using a conventional Proportional Servo – Controller (Figure 8) and a gas flowmeter. The linearity is better than 1/100 (Figure.9).

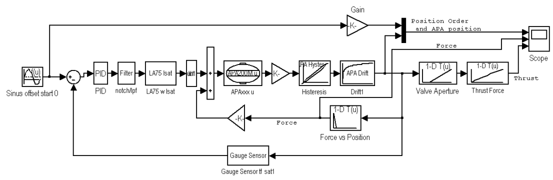


Figure 8 : Flow diagram of the servo controller used to linearize the piezo valve.

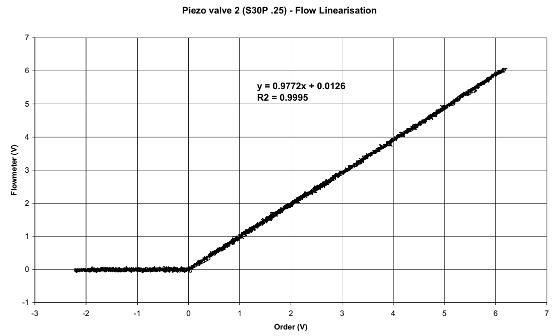


Figure.9 : Relationship between the order and the resulting flow (results monitored with a 8 byte numerical oscilloscope).

The main functional properties are :

- mass : 350 gr (to be optimised),
- flow range : 0 – 250 sccm @ 1 bar,
- dimensions : diameter : 60 mm, height : 70 mm.

7. Potential applications

7.1. Small Minimum Impulse Bit generation for micro – spacecraft's

One distinctive advantage of piezo actuator is that they display a short reaction time [5]. Therefore, their energised time can be well defined (Figure 10). One application could be within a cold / warm gas system, the generation of accurate Minimum Impulse Bit (in the range of 0.1 – 1 µN.s) for attitude and control system of micro spacecraft's.

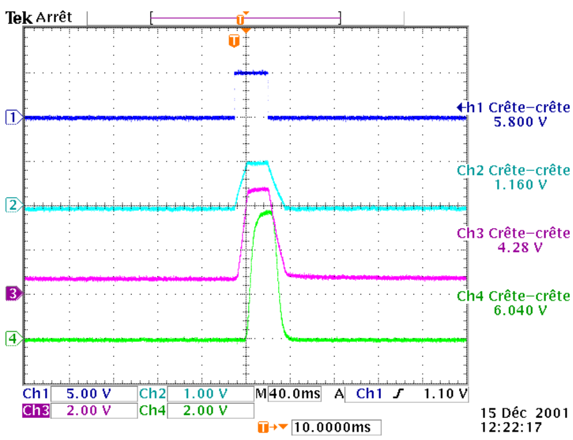


Figure 10 : Generation of Minimum impulse bit (CH1 : order, CH2 : voltage, CH3 : plunger's position, CH4 :flow)

7.2. Accurate flow control

For the same application, the piezo valve can alternatively used in a proportional system [6]. In that case, one distinctive advantage of the piezo actuated valve is the production in closed loop of a stable and accurate thrust. This property was verified through a spectrum analyser, which measured both the order and the resulting flow spectrum (Figure 11). It can be seen that the turbulent flow does not bring any additional white noise.

Figure 11 : Order and resulting flow : Power spectral density

7.3. Electronic pressure regulator

The need for electronic pressure regulators seems less pregnant than flow control valves, since there are many mechanical or electronic pressure regulator available on the market. Nevertheless, some few potential advantages can be brought by a piezo actuated pressure regulator :

- fine pressure control (limited by the pressure transducer accuracy, typically +/- 0.1 %),
- avoidance of slam start, thus removing some limit cycles arising under low flow rates – this situation has been encountered recently on cold gas system,
- potential higher bandwidth.

7.4. Gasoline injection system

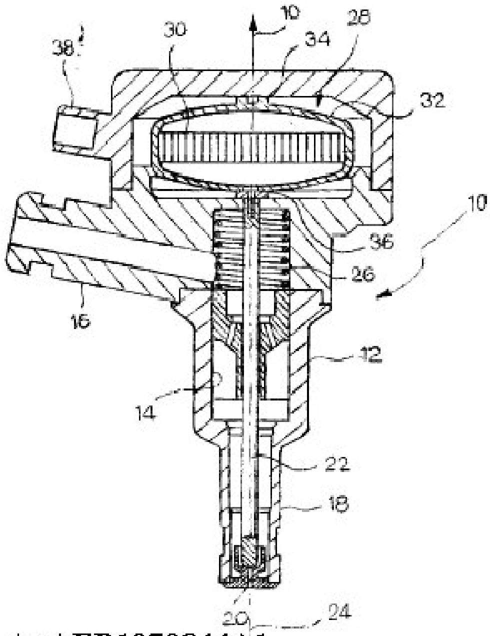
Another application is the gasoline injection system (Figure 12) : in that case, the fact that the amplified piezo actuator is a pulling actuator, is very useful to design the needle. Moreover, the lower pressure required for gasoline engines (with respect to diesel engine) could take benefit from the amplification devices to reduce the volume of active material.

8. Conclusion

Two different small piezo actuated valves have been designed and tested, to show the advantages of piezo valves over well established solenoid valves : a fine proportional behaviour and the generation of repeatable Impulse Bit are demonstrated. These valves have been developed by using several modelling tools, that can further used adapt the concept to new requirements.

This study also identified some additional works to be performed, in order to put piezo actuated valves in applications. Several technological aspects would require additional investigations :

- thermo mechanical behaviour,
- stiff sealing interfaces,
- mass optimisation,
- deeper fluid dynamics computation extended to compressible fluids.



Patent EP1070844A1

Figure 12 : Gasoline injectors based on an amplified piezo actuator

9. Acknowledgements

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10. References

[1] C. Niezrecki et al., "Piezoelectric actuation : state of the Art", The Shock and Vibration Digest, vol. 33(4), pp 269-280, 2001.
[2] Cedrat catalogue, www.cedrat.com.
[3] ADINA software, www.adina.com.
[4] W.C. Stone, "Fast variable-amplitude cold gas thruster, AIAA Journal of Spacecraft and rockets", vol. 32(2), pp 335-343, 1995.
[5] F. Butera, Patent EP1070844A1, 1999.
[6] E. D. Bushway, R. Perini, "Proportional flow control valve (PFCV) for electric propulsion systems", 3rd spacecraft propulsion symposium, Cannes, 2000.