Overview of High Performance Actuator and High Performance Valve Technologies

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Abstract:
This paper describes concepts of two different technologies developed for control of gas flow in High Performance Actuator (HPA) and control of gas discharge from airbag system through High Performance Valve (HPV). The HPA technology utilizes piezoelectric valve to govern flow in the pneumatic cylinder, used as an impact absorber or smart damper, while the HPV uses membrane surfaces driven by flow and controlled by explosive rings to mode discharge of an airbag system. Both techniques, different in their nature realizes comparatively similar function in flow different scales but similar time scale, where each cycle of operation is near single milliseconds. The paper also covers experimental results and a simple numerical study on the High Performance Valve (HPV) concept developed for a control of an adaptive inflatable impact energy absorber (gas-bag). Patent pending concept of the HPV is utilizing a flow energy drive method, using the flow energy to move and seal working parts of the valve.

Keywords: Adaptive devices, Piezo-valve, Airbag, Valve, Explosion, Control

Introduction

Presently, the demanding global market situation encourages and forces engineers to design and fabricate devices that are capable to withstand the speed of economical competition. The needs of the society and the global market inspire the designers to work on more and more sophisticated technical solutions, which can operate much faster than previously. With the demand of speed, the new structures are endangered to higher levels of accidental vibrations or exploitative impacts. At the same time, the fast operating structures are endangered to more dangerous accidents. For these reasons new technologies are required that would enable to improve the controllability of the engineering structures and to protect the potential users.

The impact and vibration protection systems are analysed for many decades [1 - 3] as passive devices. However, the recent developments in the new materials technology encourage to utilize them in the systems devoted to protecting the users of the modern vehicles [4, 5]. On the other hand it is highly valuable from the environmental point of view to reduce the usage of materials that are difficult to recycle [6].

For these reasons two technologies based on gas are presented in this paper. Both of them give some input to the advancement of the protection technologies available for the present demanding engineering market.

The High Performance Actuator (HPA) concept

Patent pending concept of HPA is an adaptive pneumatic shock absorber (Fig. 1), which utilizes a concept of governing the gas migration between two chambers of the device in order to obtain a dissipative response. The device differs from passive shock absorbers with the piezoelectric valve positioned inside of the piston (Fig. 2), which enables a controllable gas flow between both sides of the piston [7]. The dissipative response of the device under impact loading is obtained through utilization of a dedicated control strategy that assumes two steps of operation: compression of the gas to a predefined level and the second - maintaining the gas pressure drop between the volumes on both sides of the piston by regulation with the valve.

Fig. 1: *HPA device*

The piezo electric valve

The piezo electric valve utilized for the HPA is designed for being incorporated into the piston of the absorber. It has cylindrical shape and the flow passage is directed along the longer axis of the housing. The principle of the valve's operation is detaching a pair of tighten valve plates that are the flow restrictors. The operational frequency of the piezo stack in the particular mechanism is 500 Hz and the maximal value of the mass flow rate is 18 g/s by the pressure drop on the valve 950 kPa. The idea of the valve's design is presented in Fig. 2.

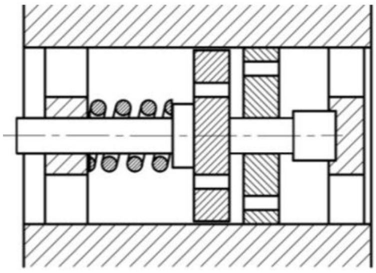

Fig. 2: HPA valve scheme

The performance of the piezo-valve was tested on a gas flow stand that enabled verification of the thermodynamic parameters. The experiment was a tank test with to gas reservoirs: inlet and outlet. The data acquisition system was configured to analyze temperatures and pressures of the gas within the valve. The piezo-valve's performance is presented in Fig. 3. The graph depicts the mass flow rate of the gas on the valve in the domain of the delivery pressure pinlet and the pressure drop on the valve pinlet – poutlet. The characteristic feature of the surface is that it consists of two regions. In the first region the mass flow rate value is dependent on the pressure drop and in the second region the mass flow rate is dependent on the value of the inlet pressure exclusively. The phenomenon can be clarified by the fact of that the flow is dynamically chocked when the velocity of the gas reaches the value of sound speed. The colour surface in figure 3 presents the experimental data and the black grid is the result of numerical simulation.

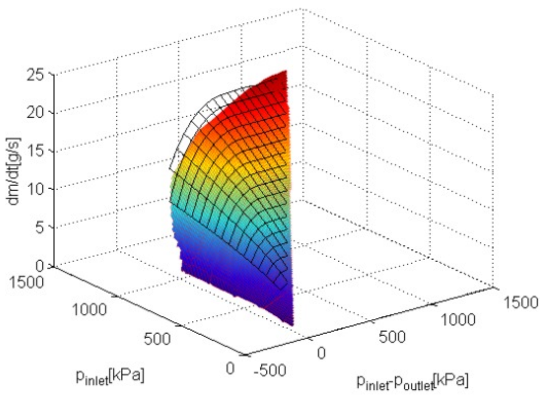

Fig. 3: HPA piezo-valve performance

Assessment of the HPA concept

The HPA actuator with a dedicated control system was tested under an impact loading on a drop test tower. The device was fixed to a platform that was guided on the structure of the tower. During the experiment, the device was drop with the platform and absorbed the impact energy in the controllable routine. The experiment consisted acquiring the values of the following parameters: displacement of the drop-weight, pressure drop on the piezo-valve, deceleration of the drop weight. The time history of the parameters is presented in figure 4. Each of the graphs in figure 4 depict a comparison between two cases of the operation: passive and controlled under exactly the same condition of the impact loading. In the first graph a mitigation of the displacement is depicted. The second graph presents the pressure drop history in time. The darker line is the response of the controlled system and it is noticeable in the period 0 – 0.1 s that the controller reduced the reaction of the absorber in the order of 40 %, which was due to dissipation of the energy within the absorber. As the result, which is depicted in the third graph, the deceleration of the drop-weight which was the protected object in this experiment, was reduced by 40 %.

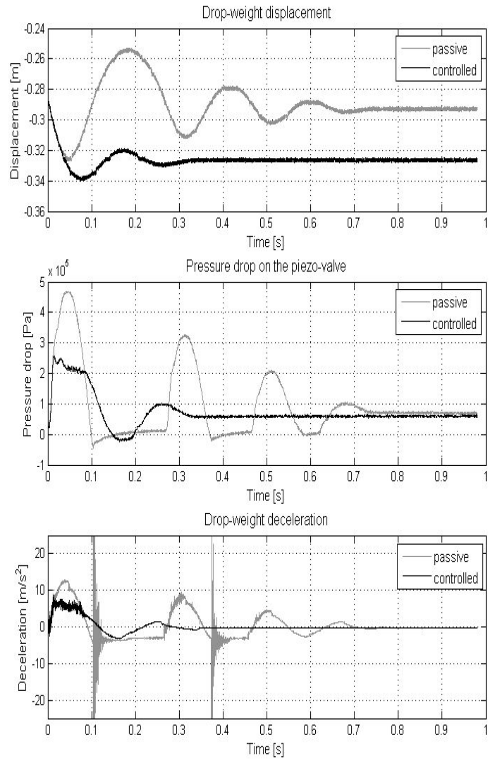

Fig. 4: HPA performance under impact loading

The High Performance Valve (HPV) concept

Patent pending concept of the HPV is utilizing a flow energy drive method, using the flow energy to move and seal working parts of the valve. This concept reduces needed power of a control system and significantly improves the valve response time, allowing for high flow. Basic configuration of the valve allows for two operation steps.

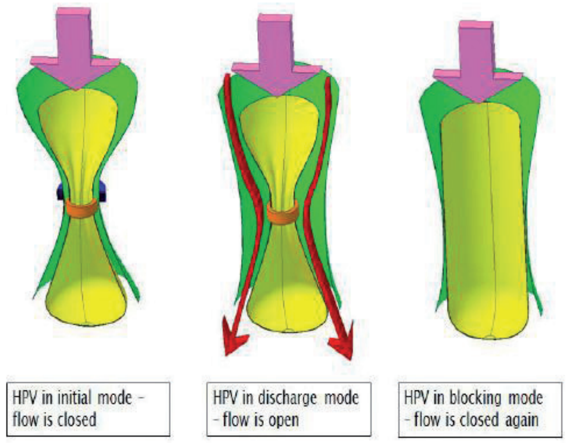

Fig. 5: *HPV operation sequence*

The HPV (Fig. 5) consist of two surfaces made of elastic membrane and two exploding control rings (patent pending). Initially valve remains closed, while the airbag is being inflated. When the control system sends a triggering signal, external control ring is released allowing external working surface to open and start gas flow.
After another triggering signal, an internal control ring may be released allowing internal valve surface to expand and therefore close gas flow. An internal HPV surface uses the dynamic pressure to expand in the initial phase. The pressure difference caused by the channel geometry, due to the Bernoulli law, helps fully developed objects to seal a gap between surfaces. When flow stops, and pressure gradient exists, the final configuration of the valve due to static pressure keeps surfaces contacted [8, 9].

Assessment of the HPV concept

An Arbitrary Langrangian-Eulerian continuum description was used in order to simulate the gas flow, and Langrangian approach was used to model HPV surfaces. Figure 6 shows concept of the HPV, during simulation of the flow induced extension of the inner surface.

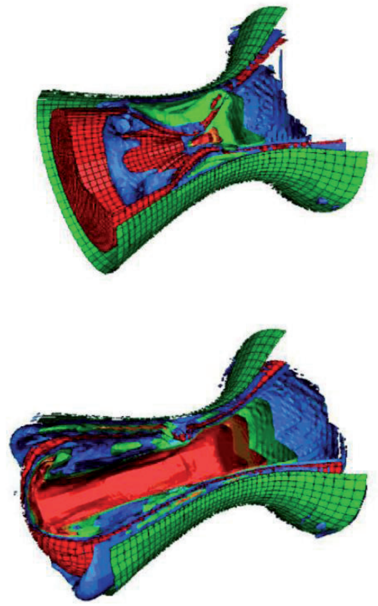

Fig. 6: *ALE FSI model of the HPV closing sequence*

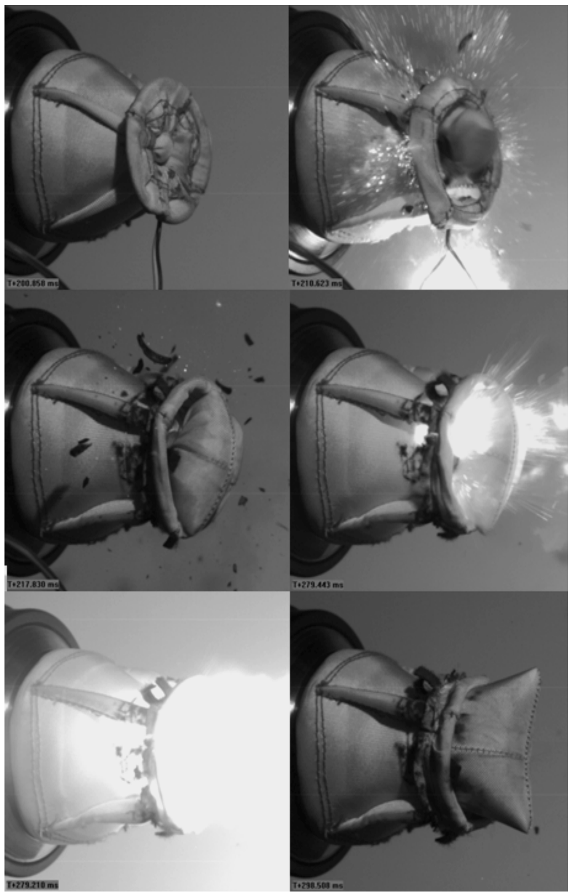

Fig. 7: *HPV closing sequence*

An experimental test of the concept was performed on the tank discharge testing stand [10], where tank was filled with air to overpressure of 200 kPa. After stabilization of tank temperature, computer system started testing sequence during which a stand control valve was opened, initiating discharge of the tank through the HPV. Test was recorded by Phantom V5.1 high-speed camera, registering footage at 4.3 kfps. Selected pictures of an operation sequence are shown in figure 7.

A history of pressure change inside the test tank is shown in figure 8. HPV operation is visible in slope of the pressure curve.

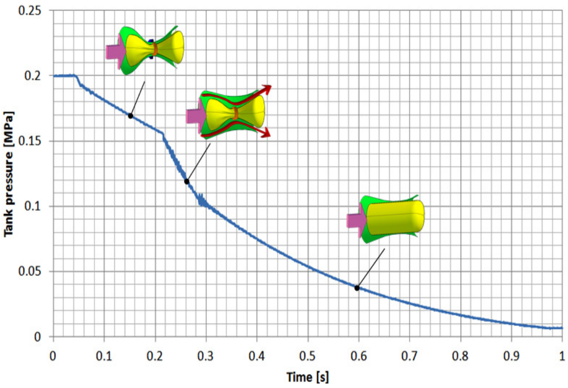

Fig. 8: Test tank internal pressure as a function of time

Conclusions

Both presented technologies have high potential for use in real world applications needing control of a gas flow. The HPA is suitable for repetitive control of the flow, in applications where the gas flow is not as high as in the HPV, but precision plays more important role – i.e. pneumatic landing gear strut. The HPV technology is suitable for high flow, high speed, non repetitive events like control of discharge of crash airbag.

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