A Fluid-damped valve

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1. Abstract

This document outlines a new valve design principle that reduces or eliminates fluid hammer (also known as water hammer or hydraulic shock) in certain types of valves, particularly one-way valves (also known as non-return valves or check valves).

AirSpayce Pty Ltd has been granted US Patent 12,247,637 and has applied for other international patents for this invention, and now seeks licensees or partners to develop its use in commercial products.

2. Background

One-way valves are frequently used in fluid handling and hydraulic systems to permit the flow of fluid through pipes and systems in a single direction.

Water hammer, or fluid hammer, is a common problem in fluid transfer and hydraulics. When a valve (such as a one-way valve) closes, any sudden closure of the valve against the valve seat, combined with the inertia of the fluid upstream and downstream of the valve, can cause severe stresses in the valve, possibly damaging it. The shock waves and echoes of the closure are also propagated through the fluid in the pipe and can cause damage and noise in piping or structures far removed from the valve.

This effect is more severe if the forward flow through the valve suffers a sudden reversal, which forces the valve to suddenly close from the fully open position to fully closed. The inertia of the moving valve parts and the upstream and downstream fluid can exert even more extreme stresses on the valve, possibly damaging the seat or destroying the valve entirely.

This problem can manifest with any fluid, such as a liquid or gas, but the most severe cases are with incompressible fluids such as liquids. Water is the most common fluid where this effect can be observed, but it is also an issue in handling of chemicals, petroleum products, sea water, cryogenic fluids, steam and others. The larger the diameter of the valve, and the greater the mass and inertia of the fluid in the associated pipes, the greater the impact of fluid hammer.

This invention can be applied to any type of one-way valve to reduce or eliminate fluid hammer.

3. Main features of the invention

The invention is a valve designed such that the working fluid (i.e. the fluid passing through the valve) is used to damp (slow down) the closure of the valve, allowing the moving valve parts (and the fluid upstream and downstream) to decelerate smoothly during the valve closure. This causes the valve parts to decelerate and close more slowly until finally seating. This reduces or eliminates one cause of fluid hammer.

The valve is designed such that as the valve closes, some of the working fluid is trapped within a damping volume or cavity from which it can only escape relatively slowly through a narrow aperture as the valve continues to close. This exerts a damping force on the valve as it closes, decelerating the valve as well as the upstream and downstream fluid and reducing the impact speed as the valve closes completely on its seat.

The rate and time interval of escape from the damping volume can be tailored for the specific application, by the design of the size of the damping volume and the size and profile of the plug on the moving valve part, or with external piping and adjustable valves or restrictions.

A secondary benefit is that the opening of the valve is also damped, so that fluid hammer resulting from the opening of the valve is also reduced.

There are no additional moving parts required (the principle is embodied in the shape of the valve parts), making it more reliable, cheaper to build and easier to maintain than existing solutions to this problem.

4. Detailed descriptions

A number of the many possible embodiments of this invention are described below.

4.1. Detailed description of a damped poppet valve

In the following drawings, a sample implementation of a sliding piston type poppet valve is shown. They show the operation of this sample valve as it opens and then closes in response to changes in pressure across the valve. The same principle can be applied to other types of valves (see below).

In this embodiment of the invention, the valve closure consists of a moving piston (possibly spring loaded) that moves within a valve body in response to fluid flow or pressure changes in the adjacent pipes. Guide (shown as dotted lines) confine the movement of the piston to a longitudinal axis. When the piston is at one extreme of movement, the valve is fully open, permitting fluid flow from the upstream to the downstream side of the valve. When the piston is at the other extreme, the piston closes on the valve seat preventing the flow of fluid from the downstream side to the upstream side.

In these diagrams, the required (forward) fluid flow is from the upstream or supply or inlet side at the bottom of the page to the downstream or discharge or outlet side at the top of the page. Flow in the reverse direction is to be blocked by the one-way valve.

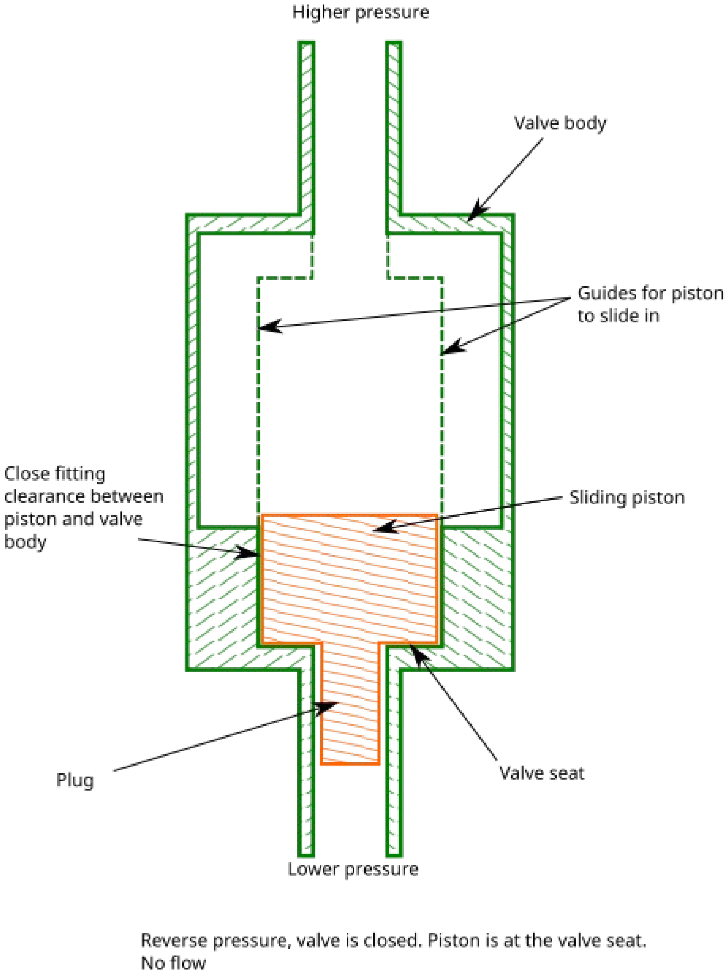
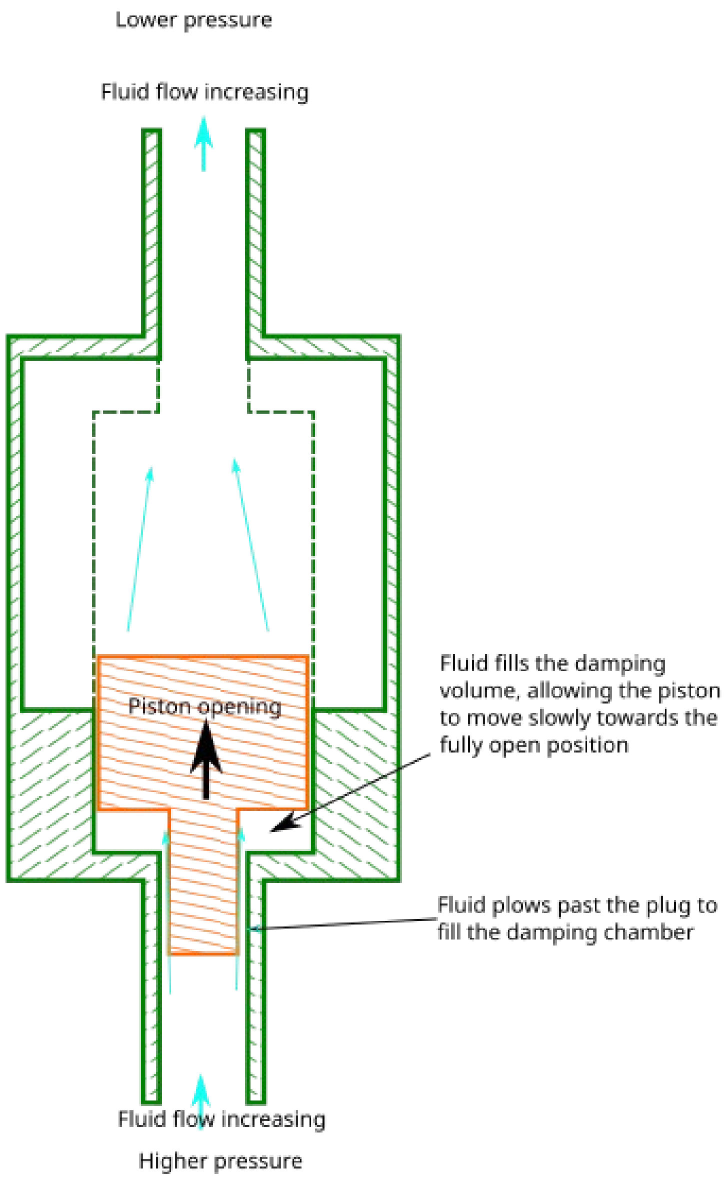


Figure 1: Valve closed

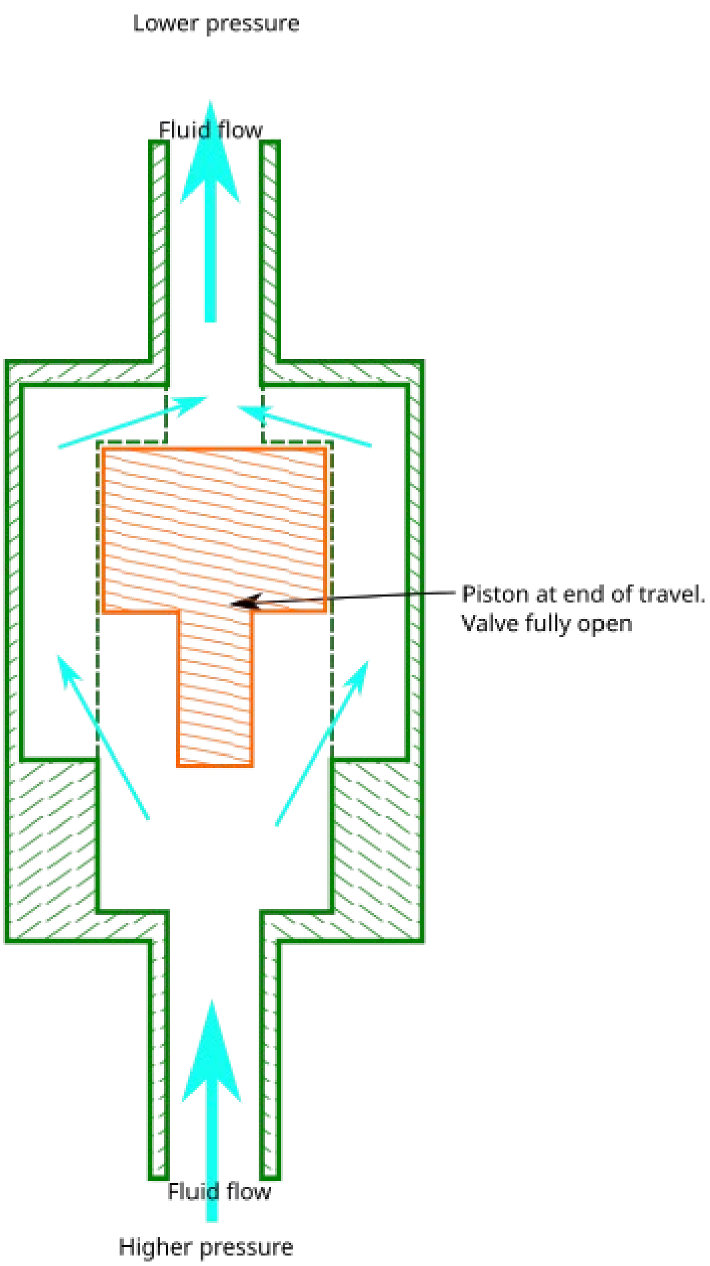
In Figure 1 The valve is fully closed and held closed against the seat by the higher pressure on the downstream side of the valve. There is no flow.



Forward pressure, fluid is gradually admitted into the damping volume as the piston starts to move up and the valve opens. Flow rate is low but increasing.

Figure 2: Valve opening

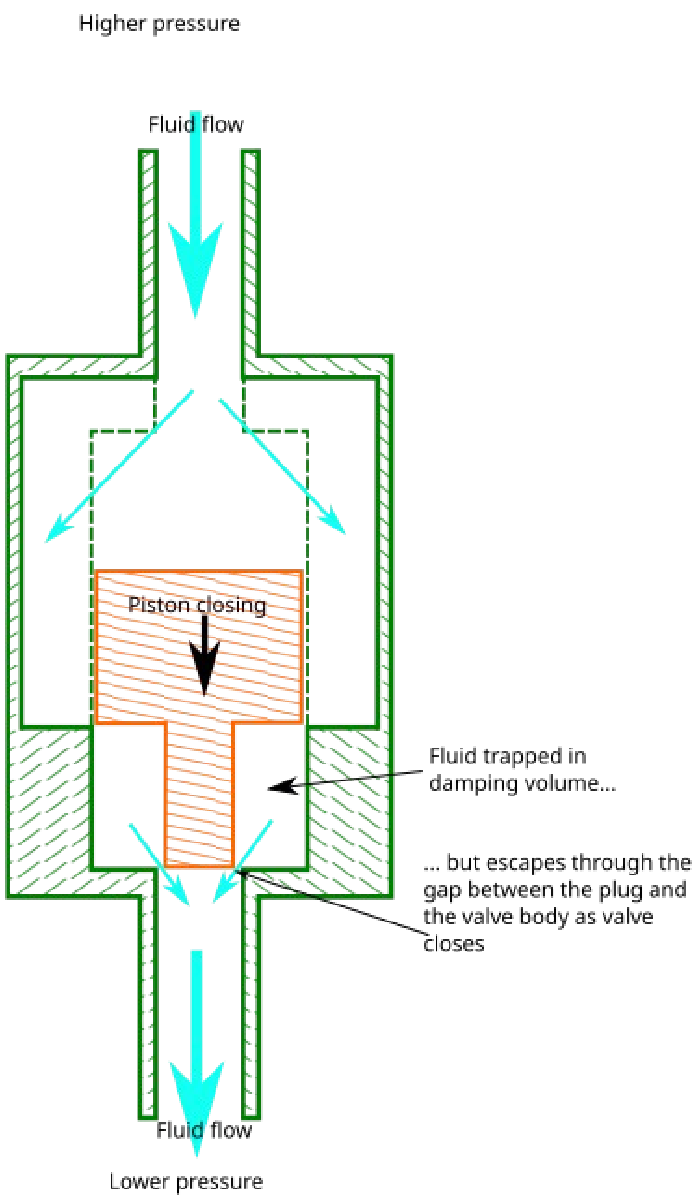
In Figure 2, the pressure on the upstream side has increased relative to the downstream side, (perhaps due to a pump starting). Fluid starts to flow from the upstream through the narrow gap between the plug and the valve body, allowing the damping volume to fill and the piston to start moving towards the downstream side. The flow rate is relatively low but increasing as the clearance between the plug and valve body increases.



Forward pressure, valve is open. Piston is at the limit of its travel in the open direction. Full flow

Figure 3: Valve open

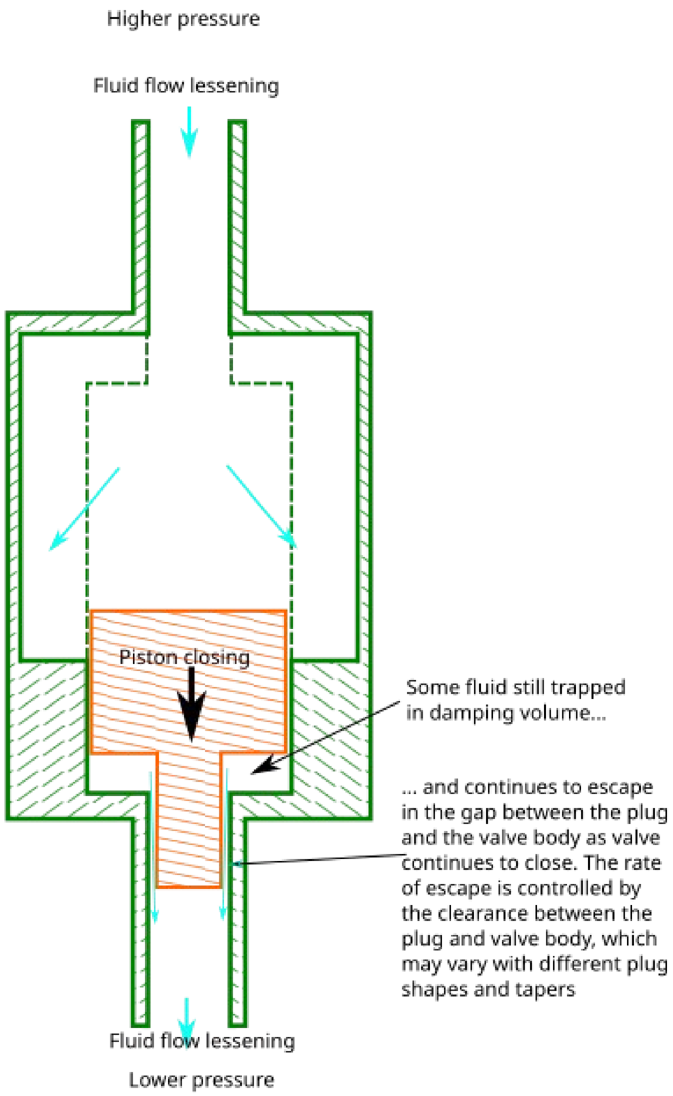
In Figure 3, the damping volume has filled completely, allowing the piston to move without constraint to its fully open position, permitting full fluid flow from the upstream to the downstream side. Flow towards downstream is at a maximum.



Reverse pressure, valve starts to close. Piston moves to close off the damping volume. Flow reduced.

Figure 4: Valve closing

In Figure 4, the pressure on the upstream side has become lower than on the downstream side, (perhaps due to a pump shutting off). Under the pressure difference and reverse flow (and optionally spring tension), the piston starts to move down until the wider part of the piston enters the top of the damping volume, at the same time that the plug part of the piston enters the orifice on the upstream side. The fit between the wider part of the piston body and the valve body is close, permitting little fluid flow through that gap. Therefore, as the valve continues to close, the fluid is forced to leave the damping volume through the narrow gap between the plug and the valve body. This narrow aperture restricts the rate of flow from the damping volume. Flow is reducing.



Reverse pressure, valve continues to close, squeezing fluid from the damping volume. Flow is greatly reduced

Figure 5: Valve closing further

In Figure 5, the valve has closed further. The fluid in the damping volume is being squeezed through an increasingly restricted aperture, increasing the damping effect. Flow is reducing further.

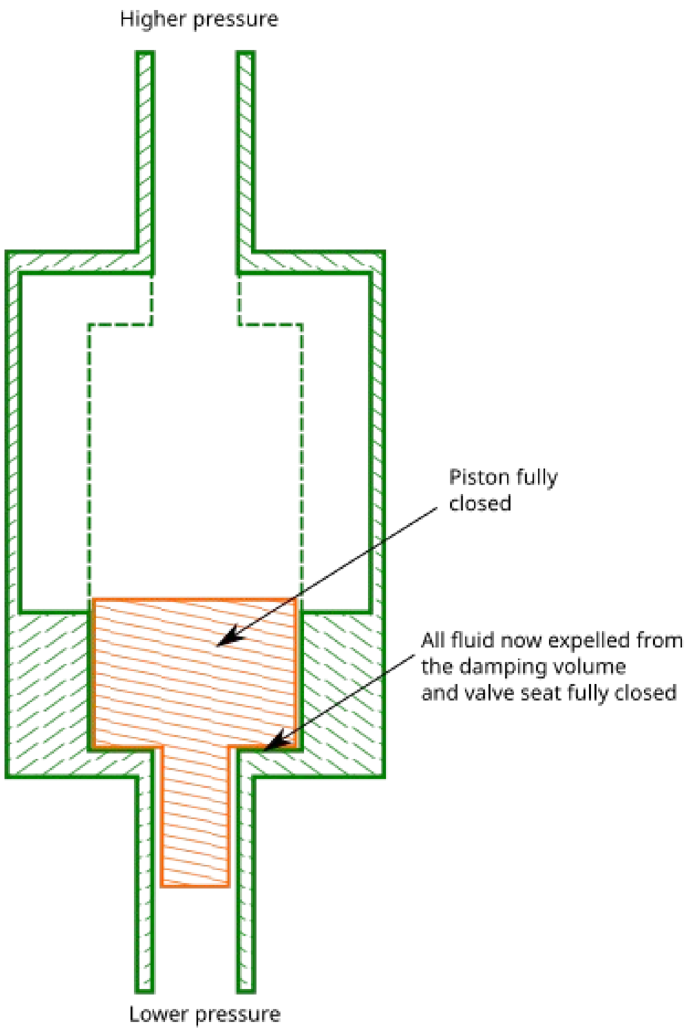


Figure 6: Valve closed again

In figure 6, all the fluid has been expelled from the damping volume and the valve is fully closed. There is no flow.

It should be noted that the rate of change of damping as the valve opens and closes can be controlled by adjusting the taper (if any) of the plug (see below).

4.2. A damped poppet valve with a profiled plug

If the plug has, say, a conical shape instead of being cylindrical, the damping during valve closure will start off weak (since less of the outlet orifice will be closed off by the plug) but as the valve approaches its fully closed state, the flow is further reduced and damping gets stronger.

Figure 7 shows a poppet valve with a sliding piston similar to the the examples shown above. The only difference is that the plug part of the piston has a tapered profile, thinner where the plug first enters the orifice, and almost completely filling the orifice when the valve is fully closed.

In Figure 7, the valve is closing from its fully open position, and again the trapped fluid if being expelled from the damping volume to the upstream side, but since the plug is narrower than in previous examples, the size of the gap between the plug and the valve body is larger, and the fluid escapes from the damping chamber more quickly, reducing the damping effect compared to the cylindrical plug example.

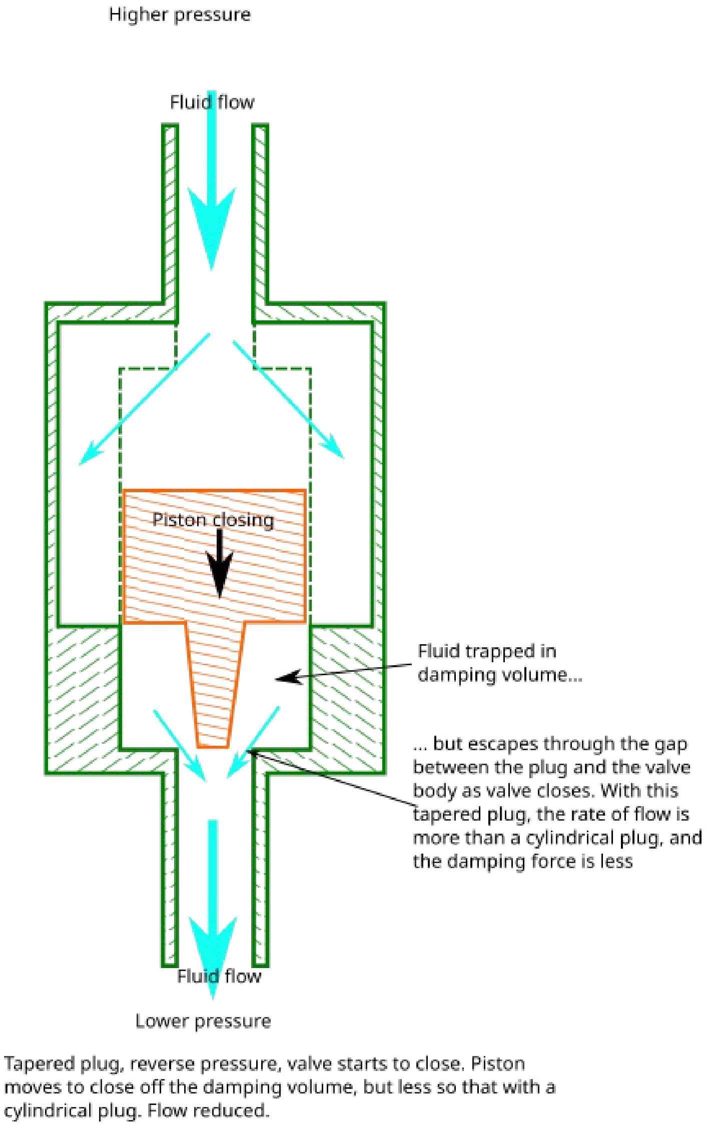
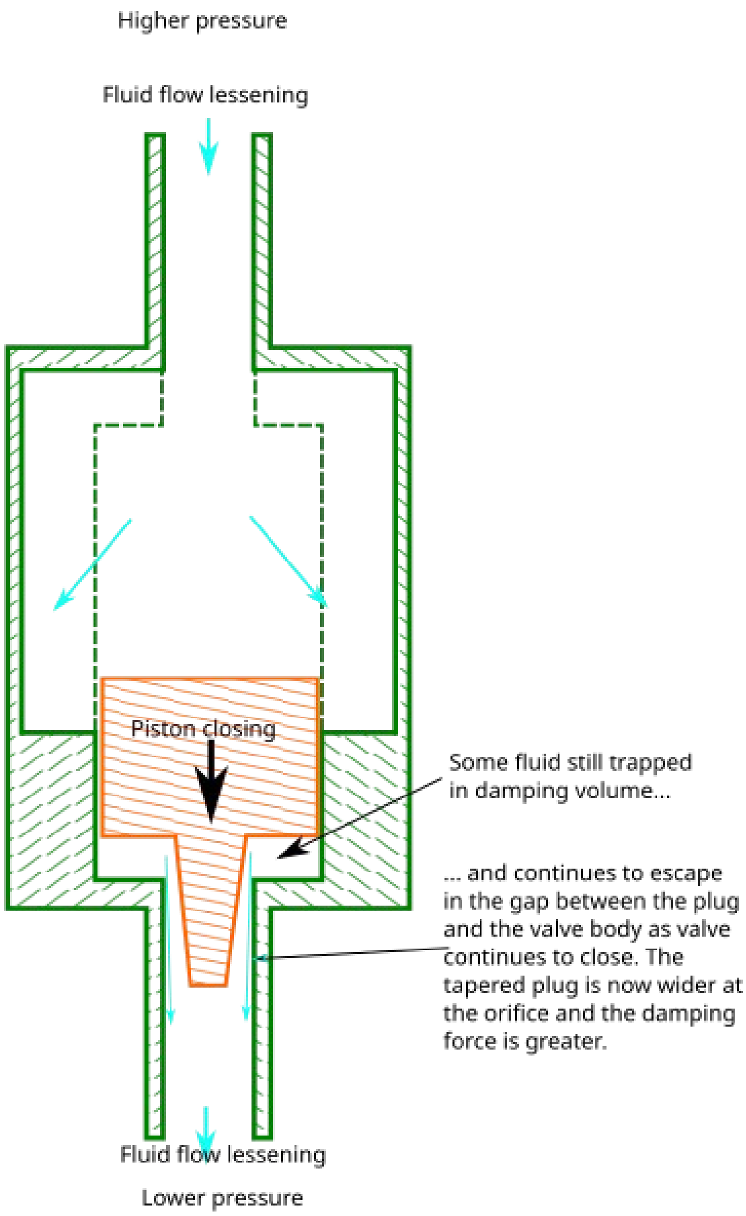


Figure 7: Tapered plug closing

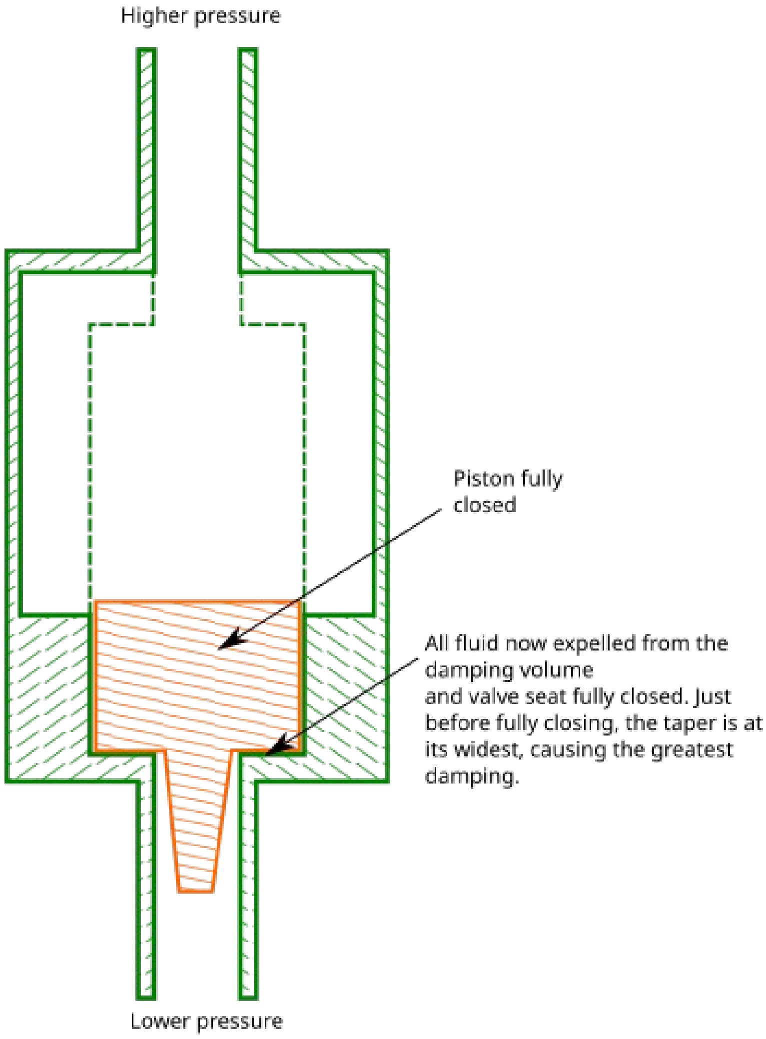
In Figure 8, the valve has closed further, and the tapered plug now fills more of the orifice, reducing the flow of fluid from the damping volume and increasing the damping effect.



Tapered plug, reverse pressure, valve continues to close, squeezing
fluid from the damping volume. Flow is greatly reduced

Figure 8: Tapered plug closes further

In Figure 9, the valve is fully closed, and all the fluid has been expelled from the damping volume. In the final moments of closing the plug almost fully fills the orifice, bringing the damping effect to its maximum for the final seating of the valve.



Tapered plug, reverse pressure, valve fully closed again. No flow.
Figure 9: Tapered plug closed

If the plug is cylindrical, the damping rate will be more constant during the closure as shown previously.

Other plug profiles and combinations of profiles can be envisaged that will deliver different damping characteristics that may be more suitable for certain applications. AirSpayce have determined the ideal profile for mitigating water hammer. See below.

4.3. A damped poppet valve with a continuously variable damping

If an external pipe with an adjustable valve and suitable one-way valve connects the damping volume to the upstream pipe, it is possible to adjust the damping rate of the valve as it closes by adjusting the flow through the connecting pipe.

Additionally, if an external pipe with an adjustable valve and suitable one-way valve in the reverse direction connects the damping volume to the upstream pipe, it is possible to adjust the damping rate of the valve as it opens by adjusting the flow through the connecting pipe.

Figure 10 shows such modifications to the poppet valve described above. Control valve 1 can be used to continuously vary the damping rate when the main valve closes. Control valve 2 can be used to continuously vary the damping rate when the main valve opens.

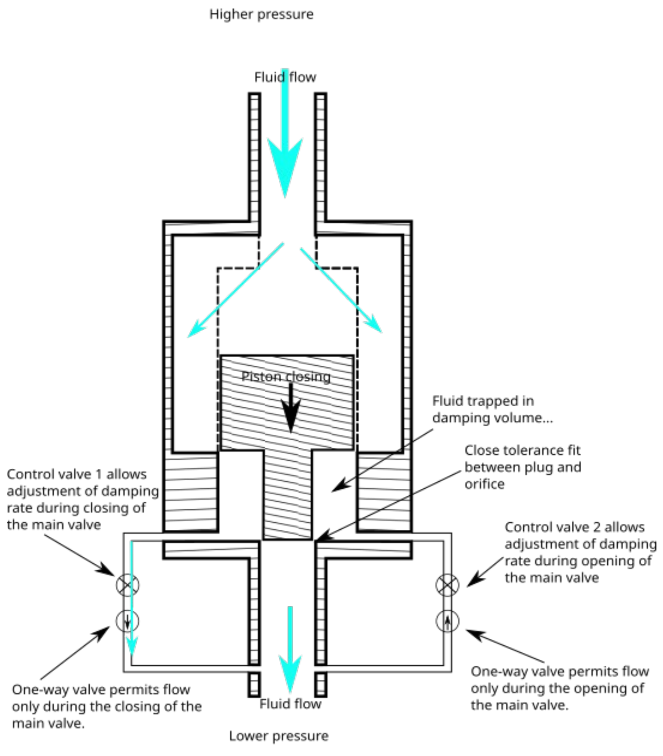


Figure 10: Poppet valve with continuously adjustable damping

Further, Control valves 1 and 2 might be automatically or computer controlled at high speed to tune the damping rate in real time as the main valve opens and closes.

4.4. A damped flap valve

Another embodiment of the invention is in a flap or clapper valve of otherwise conventional design.

In this embodiment, the valve body and flap are again shaped so that a damping volume is formed when the valve is partly closed, as shown in the figures below.

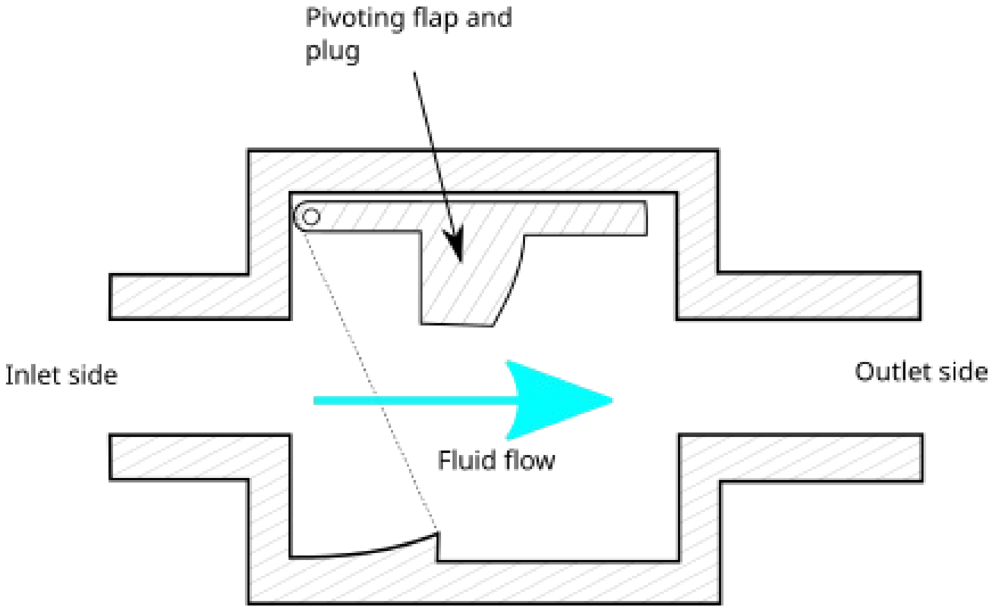


Figure 11: Flap valve fully open

Figure 11 shows the flap valve fully open. Fluid flow from the inlet side to the outlet side is at a maximum and the flap and plug is moved fully out of the orifice under the influence of fluid pressure and flow.

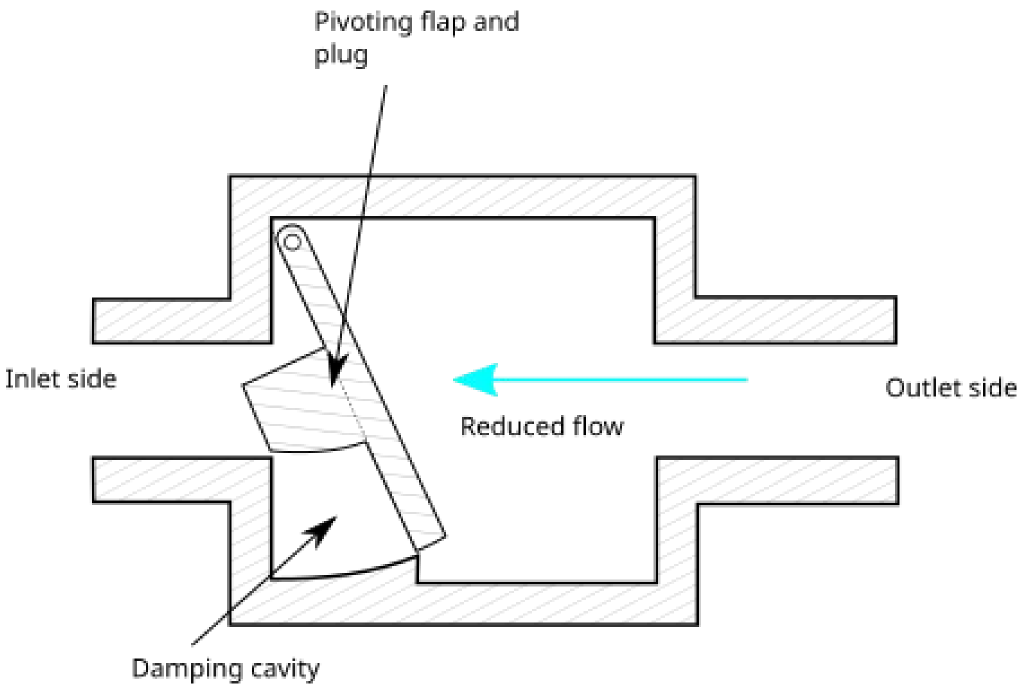


Figure 12: Flap valve closing

In Figure 12, reverse pressure has been applied: the fluid pressure on the outlet side is higher than on the inlet side. The flap moves towards the closed position, and the damping volume is formed between the flap, plug and valve body. Fluid flow and therefore flap movement is reduced due to the slow fluid flow rate from the damping volume to the inlet side between the plug and the valve body.

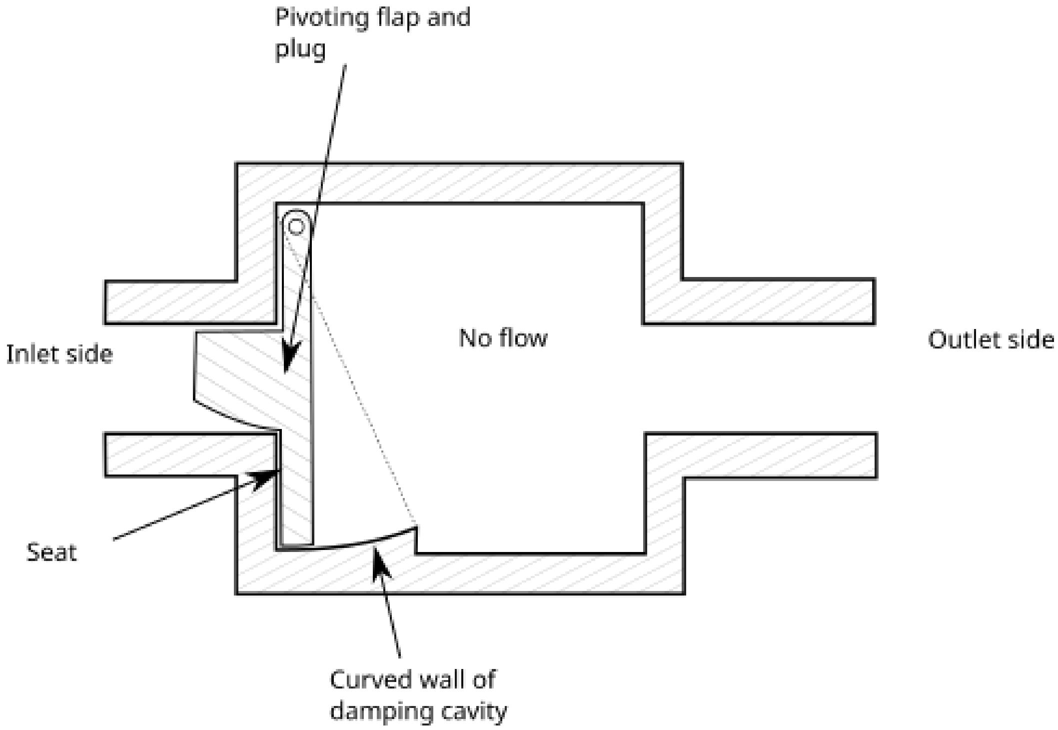


Figure 13: Flap valve closed

In Figure 13, all the fluid in the damping volume has been expelled back to the inlet side, allowing the valve to close completely and the seat to make an effective seal against reverse flow through the valve.

5. Dynamic characteristics of fluid damped valves

The damping time and rate of a particular valve in a particular application will depend on:
- Fluid viscosity
- Fluid density
- Mass of fluid in upstream and downstream pipes (length, diameter etc)
- Compressibility of the fluid
- Quantity of fluid in the damping volume
- Profile of the plug

The behaviour of this valve has been hydrodynamically modelled by AirSpayce, and equations governing the ideal dimensions and profiles for prevention or water hammer have been derived. A separate document “A Fluid-damped valve: Hydrodynamic Analysis” is available to qualified applicants.

6. Further remarks

The principle of this invention can be applied to many types of one-way valves as mentioned above, including the flap valve (also known as swing valve or swing check valve) design, or to one-way valves of the poppet (sliding piston) design, and other types.

The principle can also be applied to prior art one-way valves that employ a spring to return the piston or valve to its closed position.

It can also be applied to other types of valves (not necessarily one-way valves).

7. References

https://en.wikipedia.org/wiki/Water_hammer

The Control of Water Hammer by Automatic Valves,

Joseph E. Lescovich

Water Hammer, Practical Solutions

Bruce Sharp · David Sharp · Butterworth-Heinemann

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8. Contacts

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