

Background:

It is apparent that the 'keywords': 'Proportional Flow Valves' and 'Pulse Width Modulation (PWM)' are not unique in isolation or combination. Pulse width modulation is a method of applying a square wave whose duty cycle is modulated resulting in the variation of the average value of the waveform. This has been in use 'extensively' to actuate solenoids of hydraulic valves.

Our claim is not:

- Modelling of the dynamics of a poppet valve;
- Response enhancement of the switching (opening/closing) of valves

Our claim is a switching scheme that allows a standard On/Off Poppet valve to demonstrate proportional flow. We identify a 'region' (frequency and duty cycle) where the poppet appears to be floating mid way between the open and close state. This process allows for a variation of the mean flow, and thus provides flow control, in a valve typically applied to full follow or no flow.

PWM switching of the current to the solenoid valve allows for precise control of the energy applied to the solenoid using digital circuits which is far more stable than analog options. The excitation frequencies we apply are far higher than that typically applied to the opening and closing of a solenoid operated poppet valve.

Specific Response to Documents Cited.

Document D1: Modelling and Simulation of a Fast 2/2 Switching Valve

The paper studies the performance of a two stage proportional flow valve, in particular limitations to its performance. Inherently this class of valves provide for proportional flow

In our application, we focus on the single stage "Poppet Valve". This is, typically, used to provide "Fully On" or "Fully Off" flow control. We see no significance of the document D1 to our claim.

In our claim we demonstrated an extension of the "Fully On" or "Fully Off" flow control of poppet valves. By appropriate excitation of the poppet we can "float" the poppet in an "intermediate state" and achieve relatively proportional flow control. This occurs at a frequency higher than that of the "recommended switching rate" of the poppet valve. PWM is used as it provides precise control of energy to the solenoid coils using digital switching.

Document D2: Fundamental Performance Limitations for a Class of Electronic Two-Stage Proportional Flow Valve.

The paper describes the mathematical modeling of a relatively fast flow control valve. It does not discuss the possibility of adopting enhanced switching for "proportional flow control".

Our claim is not in the mathematical model: our claim is in the novelty of appropriate extension of the poppet excitation to provide "intermediate mode" positioning, and proportional flow with a poppet valve. This mode of operation has not been documented or described previously

Document D3: Patent Summary

In this document a method of improving the "dead-band" performance, associated with solenoid actuation was described. Whilst the paper describes the switching of a poppet valve, it still describes the case of a "Fully On" or "Fully Off" flow control.

In our claim we identify a faster switching rate (typically, one order of magnitude faster) when the poppet floats between the closed and fully open state. By varying the duty cycle and frequency we adjust this intermediate state closer to fully open or closed, providing for proportional flow.

Description

In this application we describe the use of a poppet valve for proportional flow. The application does not claim to be a replacement for conventional spool valve flow control but proposes the application as an enhancement to provide for better flow and actuator control in poppet valve fitted systems. Poppet valves have better tolerance to fluid contaminants, and the described techniques could be an advantage. The application features a method of "forcing" the poppet valve to work in an almost floating state to provide the valve a flow rate proportional to the float position and minimising the closing impact and reducing the sudden pressure spikes downstream.

A schematic of a typical solenoid operated poppet valve is shown in Fig 5. Repeated electrical signals as shown in Fig 7 are provided to energise the solenoid. Energising the solenoid coil causes the valve plug to lift off the valve body, resulting in fluid flow through the hydraulic valve. Accompanying the flow is a pressure pulse that correlates to the opening and closing of the plug and valve body. This is conventional knowledge. Poppet valves had, traditionally, been used in fully open or fully closed states. Conventionally, poppet valves were energised to a maximum frequency that permitted the valve plug to follow the electrical signal. Due to the nature the maximum frequency was of the order of 5Hz as depicted in our illustration with a COTS valve. "Fast switching" between the fully open to fully closed states have been used to control the average flow. This had in the past resulted in the generation of unacceptable levels of fluid borne noise due to the repeated pressure pulses as shown in figure 6.

When a PWM signal is increased beyond its rated maximum response frequency, the valve plug is unable to keep up with the solenoid energising and de-energising. A critical frequency can be observed for which the poppet achieves a 'floating state'. Within this phase the valve has a narrow band for which flow control is achievable. We have demonstrated this capability in figure 4 and figure 7. This critical frequency occurs at a frequency of at least an order of magnitude higher than the manufacturer's stated frequency of response for a poppet in convention usage. The alternative of varying the frequency and maintaining the duty cycles is also a possibility, at about the critical frequency and duty cycle combination.

A proportional relationship between flow and duty cycle, at the duty cycle is dependent on a complex interactions among the plug mass, solenoid excitation and fluid parameters. We envisage extending the proportional flow region with customised plug and body profiles. The valve plug is almost "floated" at a position that is dependent on the pulse width within the 'floating state'. The pressure spikes in the system are significantly reduced, as observed by comparing Fig 6 and Fig 7, when operating at a lower frequency and at the critical frequency, respectively. Since the valve plug position determines the flow rate, a flow rate proportional to the pulse width can be obtained. The effects are shown in Fig 4, showing the effects of duty cycle and flow rate at the critical frequency. By a manifold arrangement shown in Fig 2 and a micro-processor controller shown in Fig 3, a hydraulic actuator can be actuated in a bidirectional motion.