PWM Drive Method Considerations for Proportional Pneumo-Hydraulic Solenoid Valves

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Abstract: *The evolution of programmable controllers, PLCs, has allowed the digital approach to hydraulic and pneumatic applications made with proportional devices. Thus, the presence of built-in PWM (Pulse Width Modulation) blocks in most PLCs allows the direct control of the valve coils, using a simple electrical circuit to adapt the digital output of the PLC to the solenoid of the proportional device. This paper presents the calculus of the parameters for PWM drive according to the parameters of the proportional solenoid valve. An original method of increasing the native resolution of the PWM block is also presented.*

Keywords: *PWM drive, proportional solenoid valve, PWM resolution, PLC*

1. Introduction

Pulse width modulation, or PWM, is a way to digitally manipulate the power supplied to a solenoid or other device to increase efficiency. This is done by reducing the amount of power supplied during the portions of the operating cycle that do not require the full supply voltage – fig. 1 [1], [2].
While the solenoid is pushing or pulling a load, the power requirement peaks. The energy required to overcome the inertia of the load is much higher than what is required to hold the load after the plunger is fully seated. When using standard power supply the voltage is constant, so the voltage applied must match the peak power requirement. This means that the full voltage is also being applied through the full operating cycle of the device. PWM allows for the manipulation of power so that the supply can be reduced while the plunger is fully seated.
The PWM circuit modulates power by switching it off and on according to a specified duty cycle at a high frequency. The duty cycle is the ratio of on and off time. This ratio of on and off time creates an average output voltage, which becomes the input voltage for the device. The frequency this cycle is repeated fast enough so that the device does not respond to the on/off switching and instead only responds to the average.

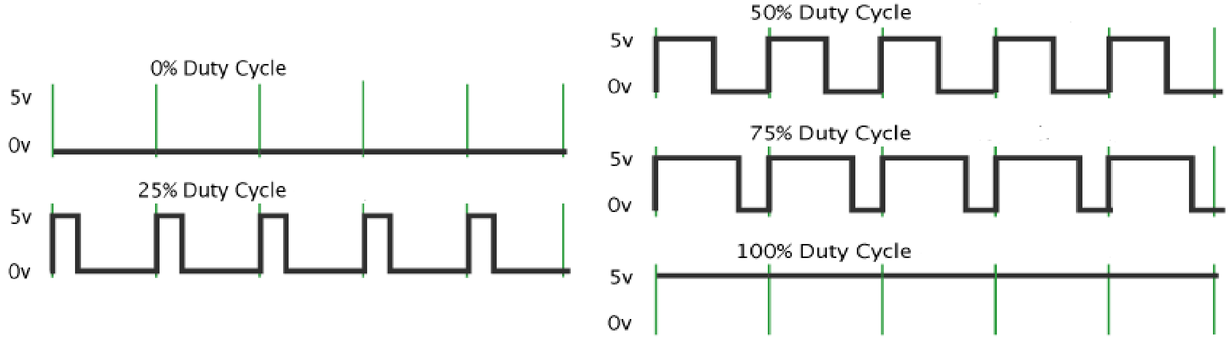


Fig. 1. Waveforms for pulse width modulation

2. Calculus of the parameters for PWM drive

As an example, a proportional relief valve, RZME-A-010 [3] with the following catalog parameters value was chosen:

Coil code	→	option /6, drivers with power supply 12 V_{DC}
Coil resistance at 20^0C	→	2Ω
Maximum solenoid current	→	2.75A
Maximum power	→	30W
Response time 0-100% step signal	→	150ms

The power value dissipated by the coil resistance through the Joule heating is

$$P_{Rmax} = RI_{max}^2 = 2 * 2.75^2 \cong 15W \tag{1}$$

The maximum value of the reactive power that actuates the poppet of the proportional relief valve is

$$P_{max} - P_{Rmax} = 30 - 15 = 15W \tag{2}$$

The maximum value of the magnetic field energy is

$$\frac{1}{2}LI^2 = \frac{1}{2}L2.75^2 \cong 3.8L \tag{3}$$

where L is inductance of the valve solenoid in henry. This magnetic field energy is mainly used to drive the valve poppet.

The maximum value of the power actuating the valve poppet is when valve executes the full pressure step response

$$3.8L/0.15 = 15 \;\Longrightarrow L \cong 0.6H \tag{4}$$

Fig. 2 shows the electrical diagram of the signal conditioner between the digital output of the PLC and the solenoid of the hydraulic device. This circuit was simulated in Ltspice® [4] to validate the calculation of the PWM parameters.

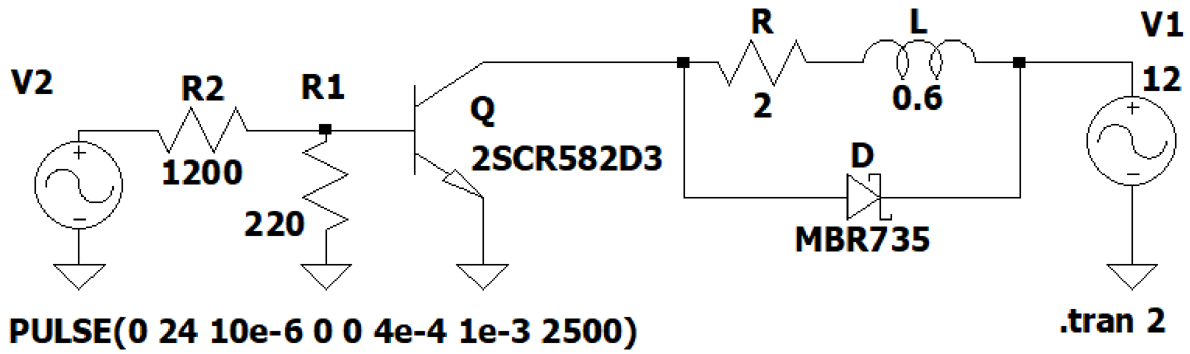


Fig. 2. SPICE model for signal conditioner

The voltage drop equation for the conduction interval T_{on} of the transistor is

$$V1 = RI + L\frac{\Delta I}{T_{on}} \tag{5}$$

Similarly for the blocking interval $T - T_{on}$ of the transistor following results

$$RI = L\frac{\Delta I}{T - T_{on}} \tag{6}$$

From equations (5) and (6) the current ripple value can be calculated

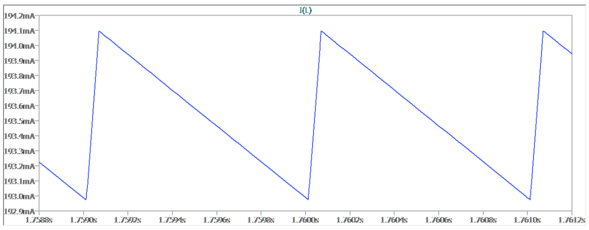
$$V1 = L\frac{\Delta I}{T - T_{on}} + L\frac{\Delta I}{T_{on}} \Leftrightarrow L\frac{\Delta I}{T_{on}} = V1\frac{T - T_{on}}{T} \tag{7}$$

From equations (5) and (7) the current value can also be calculated

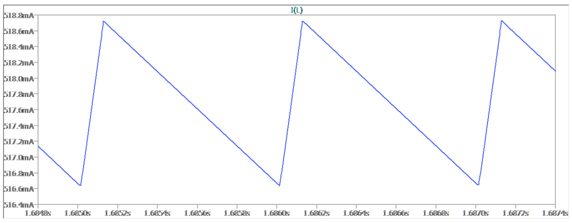
$$V1 = RI + V1\frac{T-T_{on}}{T} \Leftrightarrow RI = V1\frac{T_{on}}{T} \quad (8)$$

where $T = 1ms$ is the value of PWM signal period and $V_1 = 12V$.
The values of current and current ripple is

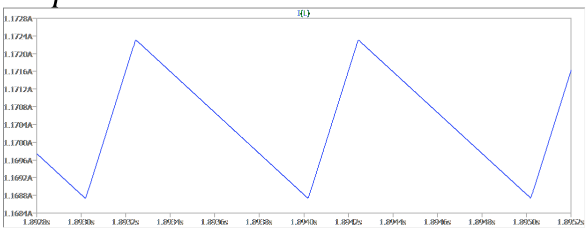
$$\Rightarrow I = \frac{V1}{R}\frac{T_{on}}{T}, dI = V1\frac{T_{on}}{L}\left(1 - \frac{T_{on}}{T}\right) \quad (9)$$



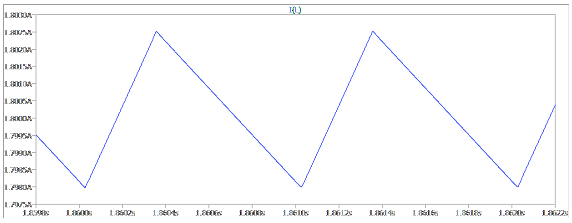
$$\frac{T_{on}}{T} = 5\% \Rightarrow dI = 0.95mA \; ; \; I = 0.3A$$



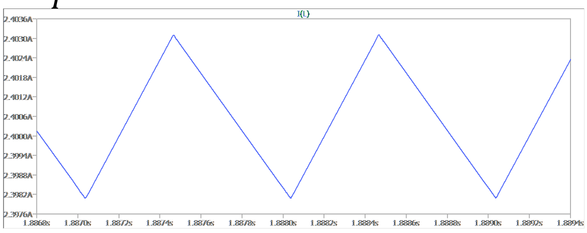
$$\frac{T_{on}}{T} = 10\% \Rightarrow dI = 1.8mA \; ; \; I = 0.6A$$



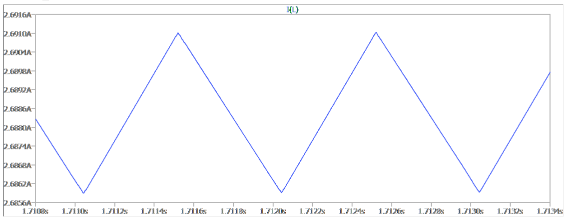
$$\frac{T_{on}}{T} = 20\% \Rightarrow dI = 3.2mA \; ; \; I = 1.2A$$



$$\frac{T_{on}}{T} = 30\% \Rightarrow dI = 4.2mA \; ; \; I = 1.8A$$



$$\frac{T_{on}}{T} = 40\% \Rightarrow dI = 4.8mA \; ; \; I = 2.4A$$



$$\frac{T_{on}}{T} = 45\% \Rightarrow dI = 4.95mA \; ; \; I = 2.7A$$

Fig. 3. The solenoid valve waveforms of current

Fig. 3 shows the simulated coil current waveforms and the calculated current and current ripple values according to (9).

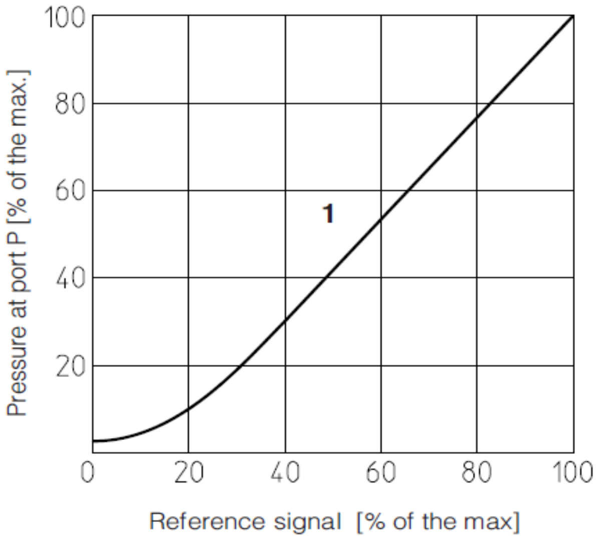


Fig. 4. Proportional relief valve regulation diagram at flow rate Q = 1 l/min

Fig. 4 shows the adjustment diagram for proportional relief valve, RZME-A-010 [3].
It is noted that the variation range of the PWM duty factor must be in the range of 10%...45% to fall within the linear regulation area, fig. 3. This corresponds to the range 20%...100% of the reference signal, fig. 4.

3. Increasing the native resolution of the PWM

A case study will be presented for the previously considered proportional valve RZME-A-010 controlled with a TM221C24T PLC with PNP transistor output [5].
The assumptions are:

- PWM output resolution value for PLC is 1% [Modicon M221 Logic Controller Advanced Functions Library Guide, chapter Pulse Width Modulation (%PWM) at [5]].
- The variation range of the PWM duty factor in the range of 10%...45% to fall within the linear regulation area, see fig. 3 and fig. 4.

Consequently, the PWM resolution is only 45% - 10% = 35 steps of pressure values for the linear control range. In industrial applications, this resolution value is often insufficient. The idea of increasing the PWM resolution is to average multiple periods of the PWM signal, periods that have duty factor values two successive steps from the native resolution values.
For example, the duty factor value of 20.3%, if one wants to increase ten times the 1% native resolution value of the PWM block, it is necessary to produce ten periods, respectively three periods with a duty factor value of 21% and seven periods with a duty factor value of 20%.
Thus, the period of pulses required for averaging the current in the controlled coil will be multiplied ten times. This signal processing is very similar to that of the digital decimation filter [6].

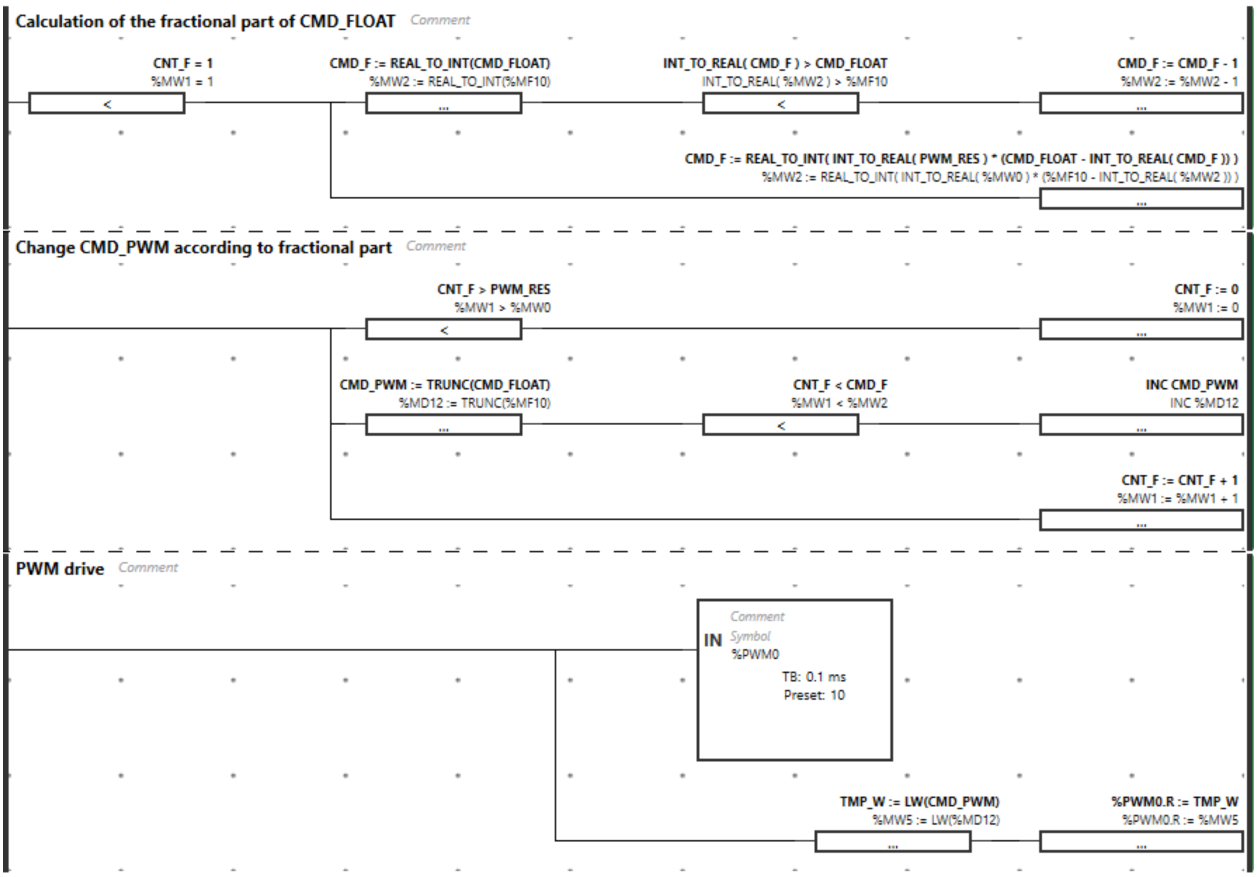


Fig. 5. Increasing the native resolution of the PWM – ladder diagram implementation

Fig. 5 shows the program, in ladder diagram language, that implements the PWM resolution increasing sequence.

4. Conclusion

To achieve adequate electrical control of proportional pneumo-hydraulic devices, a systemic approach is required. Thus, the method of calculating the parameters of the electronic control block based on the catalog parameters of the proportional device has been presented.
Also, if the native resolution of the built-in PWM block in the PLC is too small, a method to increase its original resolution has been proposed.

Acknowledgments

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References

[1] Magnet-Schultz of America. Accessed March 3, 2024. https://magnet-schultzamerica.com/.
[2] Sun, Jian. "Pulse-Width Modulation." In: Vasca, F., and L. Iannelli (eds.). *Dynamics and Control of Switched Electronic Systems*. *Advances in Industrial Control*. London, Springer, 2012.
[3] Atos S.P.A. Accessed March 3, 2024. https://www.atos.com.
[4] Analog Devices, Inc. Accessed March 3, 2024. https://www.analog.com/en/resources/design-tools-and-calculators/ltspice-simulator.html
[5] Schneider Electric. Accessed March 3, 2024. https://www.se.com.
[6] National Instruments Corp. "Decimation (Digital Filter Design Toolkit)". *LabVIEW Digital Filter Design Toolkit API Reference*, March 14, 2023. Accessed March 3, 2024. https://www.ni.com/docs/en-US/bundle/labview-digital-filter-design-toolkit-api-ref/page/lvdfdtconcepts/dfd_decimation.html.