AN103 – Valve Driver: Pulse Width Modulations and Dither

Introduction

Traditional solenoid driver electronics rely on linear control, which is the application of a constant voltage across a resistance to produce an output current that is directly proportional to the voltage. Feedback can be used to achieve an output that matches exactly the control signal. However, this scheme dissipates a lot of power as heat, and it is therefore very inefficient. A more efficient technique employs **pulse width modulation (PWM)** to produce the constant current through the coil.

PWM Signal

1. A PWM signal is not constant. Rather, the signal is on for part of its period, and off for the rest. The **duty cycle**, D, refers to the percentage of the period for which the signal is on. The duty cycle can be anywhere from 0, the signal is always off, to 1, where the signal is constantly on. A 50% D results in a perfect square wave. (Figure 1)
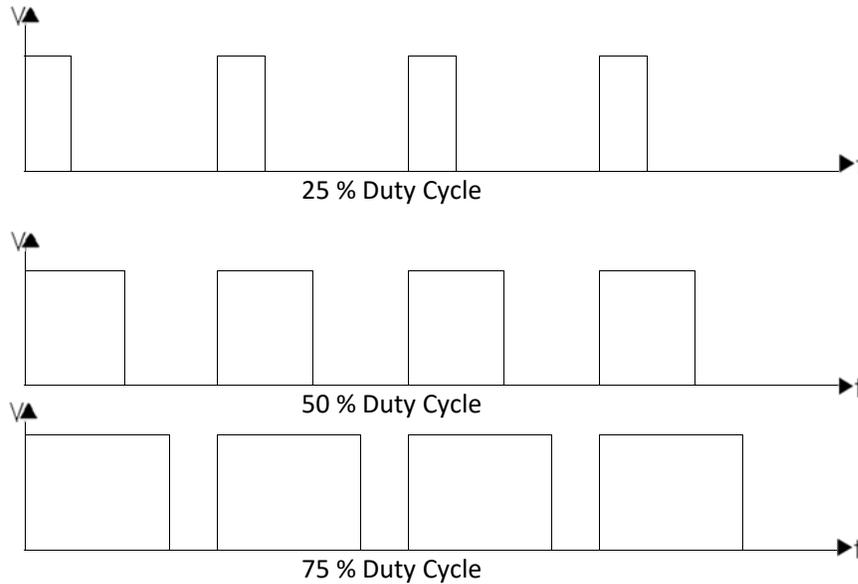

Figure 1 – Duty Cycles

2. A solenoid is a length of wire wound in a coil. Because of this configuration, the solenoid has, in addition to its resistance, R, a certain **inductance**, L. When a voltage, V, is applied across an inductive element, the current, I, produced in that element does not jump up to its constant value, but gradually rises to its maximum over a period of time called the rise time (Figure 2). Conversely, I does not disappear instantaneously, even if V is removed abruptly, but decreases back to zero in the same amount of time as the rise time.
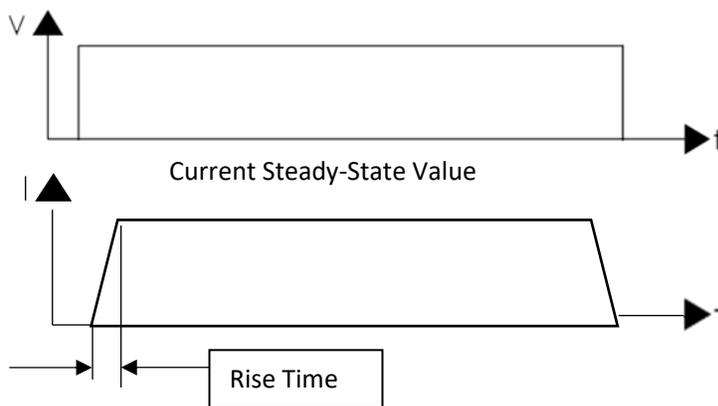

Figure 2 – Continuous Voltage Across an Inductor

Therefore, when a low frequency PWM voltage is applied across a solenoid, the current through it will be increasing and decreasing as V turns on and off. If D is shorter than the rise time, I will never achieve its maximum value, and will be discontinuous since it will go back to zero during V's off period (figure 3).

Figure 3 – Low Frequency PWM with D<Rise Time Resulting in Discontinuous Current
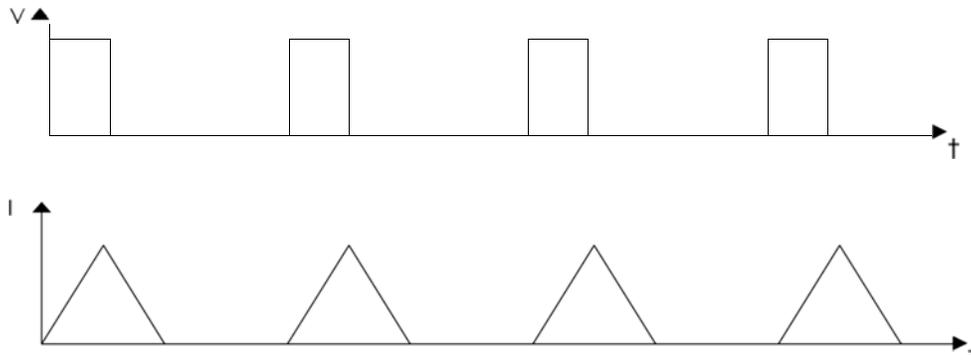
In contrast if D is larger than the rise time, I will never fall back to zero, so it will be continuous and have a DC average value. The current will not be constant, however, but will have a ripple (Figure 4).

Figure 4 – Low Frequency PWM with D>Rise Time Resulting in Continuous Current with Ripple
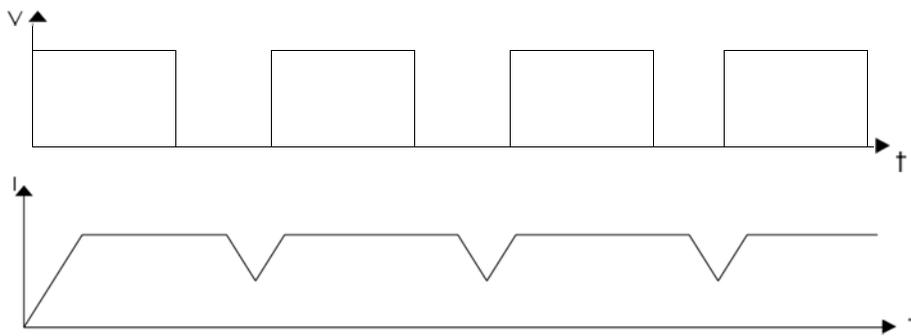
At high frequencies, V turns on and off very quickly, regardless of D, such that the current does not have time to decrease very far before the voltage is turned back on. The resulting current through the solenoid is therefore considered to be constant. By adjusting the D, the amount of output current can be controlled.

With a small D, the current will not have much time to rise before the high frequency PWM voltage takes effect and the current stays constant. With a large D, the current will be able to rise higher before it becomes constant. (Figure 5)

Figure 5 – Effect of Varying D, for High Frequency PWM Voltage, on Current

Dither
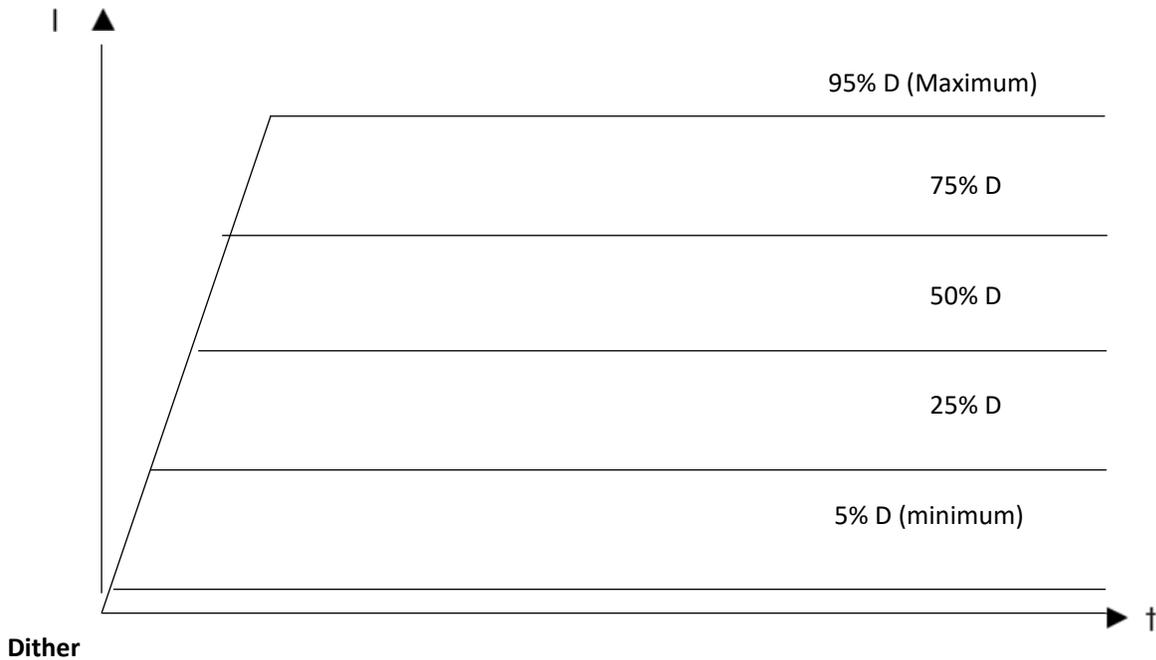
Static friction, stiction, and hysteresis can cause the control of a hydraulic valve to be erratic and unpredictable. Stiction can prevent the valve spool from moving with small input changes, and hysteresis can cause the shift to be different for the same input signal. In order to counteract the effects of stiction and hysteresis, small vibrations about the desired position are created in the spool. This constantly breaks the static friction ensuring that it will move even with small input changes, and the effects of hysteresis are average out. Dither is a small ripple in the solenoid current that causes the desired vibration and thereby increases the linearity of the valve.

The amplitude and frequency of the dither must be carefully chosen. The amplitude must be large enough and the frequency slow enough that the spool will respond, yet they must also be small and fast enough not to result in a pulsating output. The optimum dither must be chosen such that the problems of stiction and hysteresis are overcome without new problems being created.

Dither in the output current is a byproduct of low frequency PWM, as seen above. However, the frequency and amplitude of the dither will be a function of the duty cycle, which is also used to set the output current level. This means that low frequency dither is not independent of current magnitude.

The advantage of using high frequency PWM is that dither can be generated separately, and then superimposed on top of the output current. This allows the user to independently set the current magnitude (by adjusting the D), as well as the dither frequency and amplitude. The optimum dither, as set by the user, will therefore be constant at all current levels.

Version	Date	Author	Comments
1.00	July 3, 2019	Gustavo Del Valle / Sue Thomas	