Efficient and Effective Direct Acting Solenoid Valve Control

The Benefits of Using “Hit and Hold” Electrical Control on Direct Acting Solenoid Valves

Parker

ENGINEERING YOUR SUCCESS.

Efficient and Effective Direct Acting Solenoid Valve Control
Basic Solenoid Valve Operation

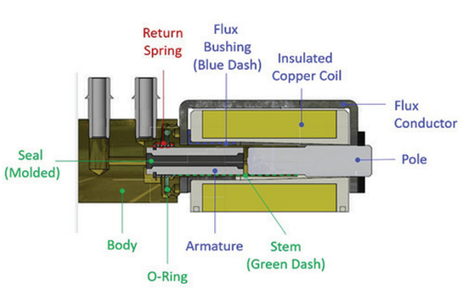
Direct acting solenoid valves require a significant amount of electrical power to change from a normally closed state to an open or actuated state. Once the valve is fully actuated, the amount of electrical energy required to maintain this state is significantly lower than the initial energy required to initiate the actuation. Therefore, in direct acting solenoid valve applications where battery life and/or heat generation is a concern, the utilization of a "hit and hold" electrical signal can result in significant power savings and heat reduction while still maintaining the required pneumatic function. This article explains basic direct acting solenoid valve theory, test methods to characterize actuation and drop-out current parameters, PWM hold control methodology, and general recommendations/ typical examples to support end users in reducing power consumption and heat generation in their applications.

Basic Solenoid Valve Operation

To understand the theory and benefits of hit and hold electrical control, we must first have a basic understanding of direct-acting solenoid valve design and operation. A typical direct acting solenoid valve is comprised of the following sub-components: (Reference Figure -1

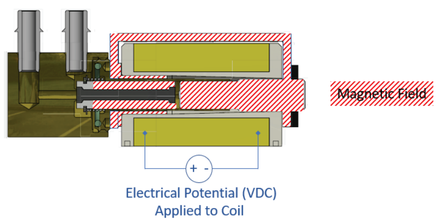
- Insulated copper coil
- Pole, Flux Bracket, Flux Bushing, Armature. (Iron Core components presented in Blue)
- Plunger Seal, Stem, O-Ring, Body. (Pneumatic components presented in Green)
- Return spring

Figure-1: 2-way/2-position direct acting solenoid valve



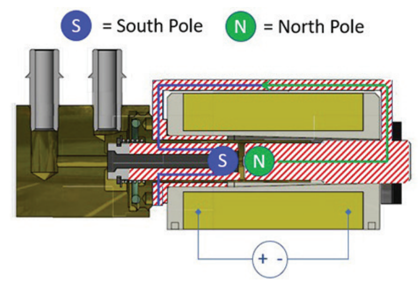
When an electrical potential is applied to the coil and current flows through the copper conductor, the coil component transforms into a magnet or solenoid. The magnetic field generated from the solenoid is then captured and directed through the iron core components of the valve as illustrated in Figure-2.

Figure-2: Magnetic field captured and directed through iron core components



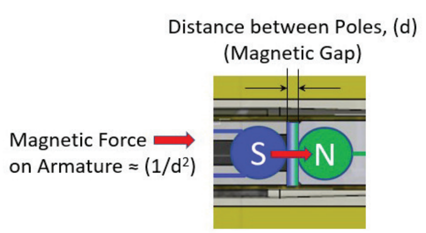
As the magnetic field is established, opposing magnetic poles are formed between the armature and pole subcomponents as illustrated in Figure-3. (Also illustrated are the lines of magnetic force, or flux density, connecting the poles in green and blue)

Figure-3: Magnetic pole locations



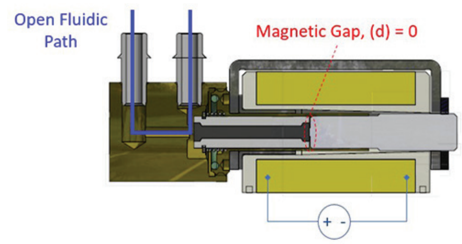
The resulting magnetic force generated between these components is inversely proportional to the distance squared between the two components as illustrated in Figure-4. This distance is referred to as the magnetic gap.

Figure-4: Magnetic force on armature



When the magnetic force on the armature exceeds the installed load of the return spring, (and any supplemental pneumatic differential force), the armature will actuate/move to contact the pole as illustrated in Figure-5. Specific to the 2-way/2-position solenoid valve illustrated in Figure-5, once the actuation occurs, the fluidic path is opened between the valve ports.

Figure-5: Actuated valve state (open fluidic path)



To close the fluidic path and return the valve to normally closed state, the voltage source is removed/disconnected from the coil. Once the power source is removed, the magnetic field collapses, and the spring returns the armature to the normally closed position.

It is important to understand that solenoid valves are current driven devices where the magnetic field strength of the solenoid is proportional to amount of current traveling through the coil. Therefore, the two valve states described above, (actuation and drop-out), will ultimately be defined by the effective current traveling through the coil.

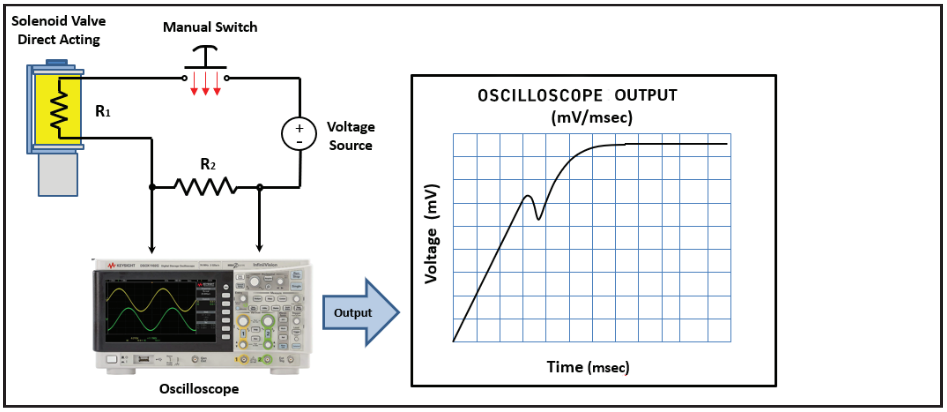
Capitalizing on valve mechanics

So now that we understand basic solenoid valve mechanics, how do these operating principles tie into reducing power consumption and heat generation within the valve? The key here is understanding the difference between the maximum current, at maximum rated voltage, and the current required to maintain the actuated state. A plot of the inductive response time of the valve is helpful in distinguishing the difference between the two states.

Efficient and Effective Direct Acting Solenoid Valve Control Capitalizing on Valve Mechanics

Figure-6 below illustrates a typical electrical circuit for conducting a response time test and the resulting voltage vs. time plot captured on the Oscilloscope.

Figure-6: Response time test circuit and typical oscilloscope output



It should be noted that in order to provide a clean voltage signal to the oscilloscope, a low resistance resistor, resistor-2 or R2, must be added to the circuit. (R2 <1% of R1)

Once the manual switch is closed, the voltage across R2 increases linearly until the armature begins to move as illustrated in Figures-7 and 8 below.

Once the armature is in motion, the inductance of the circuit increases and the voltage signal across R2 begins to decrease until the armature is fully actuated (Figure-9). Once fully actuated, the input voltage across R2 returns to the same increasing trajectory until a, steady state, maximum voltage/steady state condition is achieved (Figure-10).

The Parker X-Valve miniature solenoid 8mm valve is available in 2-way normally closed and 3-way universal configurations. The X-Valve is an ideal solution portable medical devices with limited space and power

Figure-7

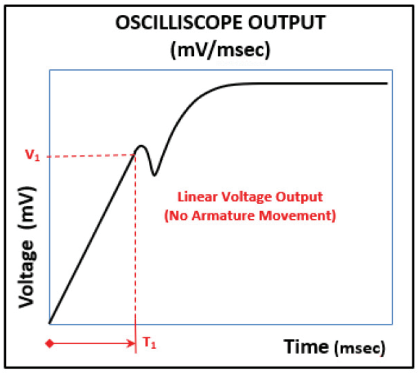


Figure-8

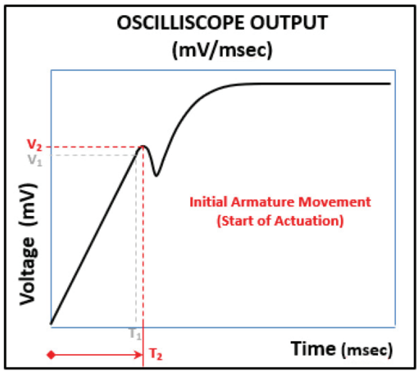


Figure-9

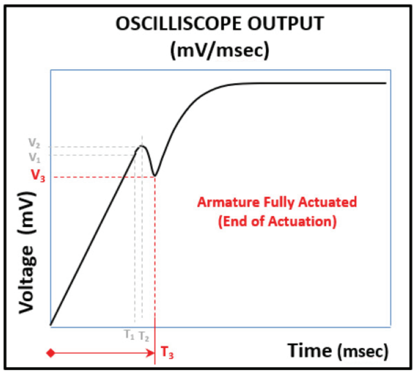
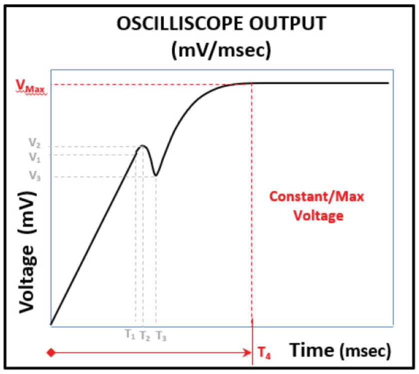
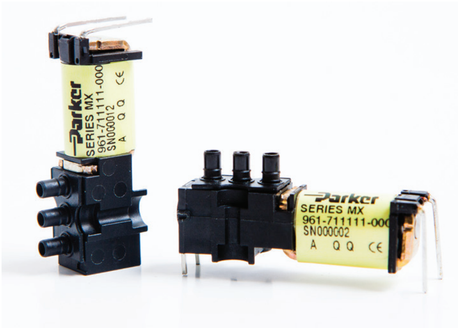


Figure-10





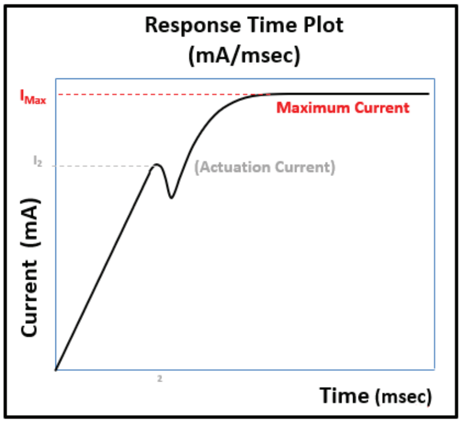
The Parker MX miniature solenoid 10mm actuated poppet valve has a high flow to power consumption ratio that can increase device battery life and is available in 2-way and 3-way configurations.

Efficient and Effective Direct Acting Solenoid Valve Control Capitalizing on Valve Mechanics

It is important to understand that the voltage required to actuate the valve will vary with changes in coil temperature; The coil resistance is dependent on the coil temperature. Therefore, as the coil temperature increases, the actuation voltage will increase proportionally to compensate for the increased coil resistance. The opposite is true when the coil temperature decreases. In either case, the actuation current will remain consistent with variations in coil and ambient temperatures.

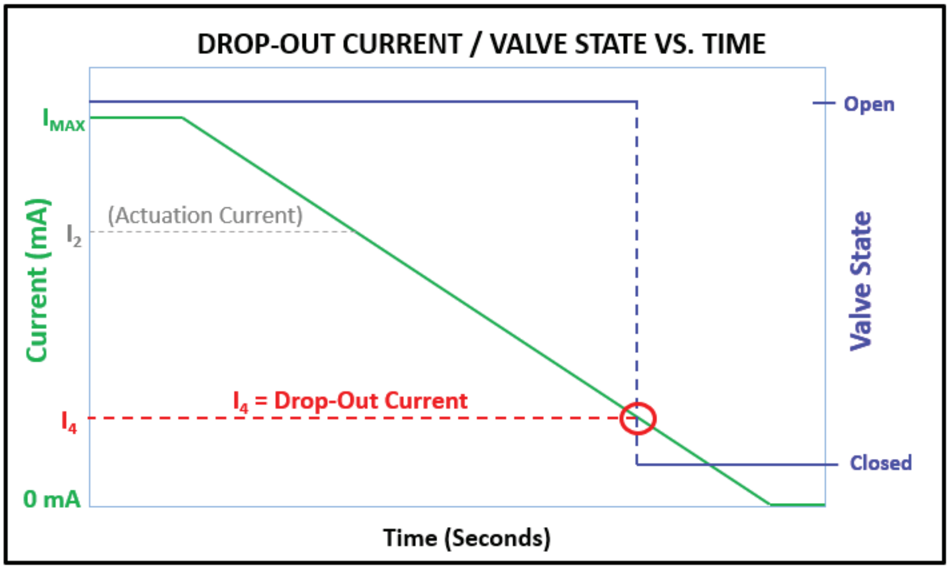
For the remaining portion of this discussion, the maximum voltage parameter will be replaced by the corresponding maximum current parameter so that the difference between the maximum current and the drop-out current can be assessed. Figure-11 below illustrates the location of the corresponding maximum current and actuation current parameters.

Figure-11



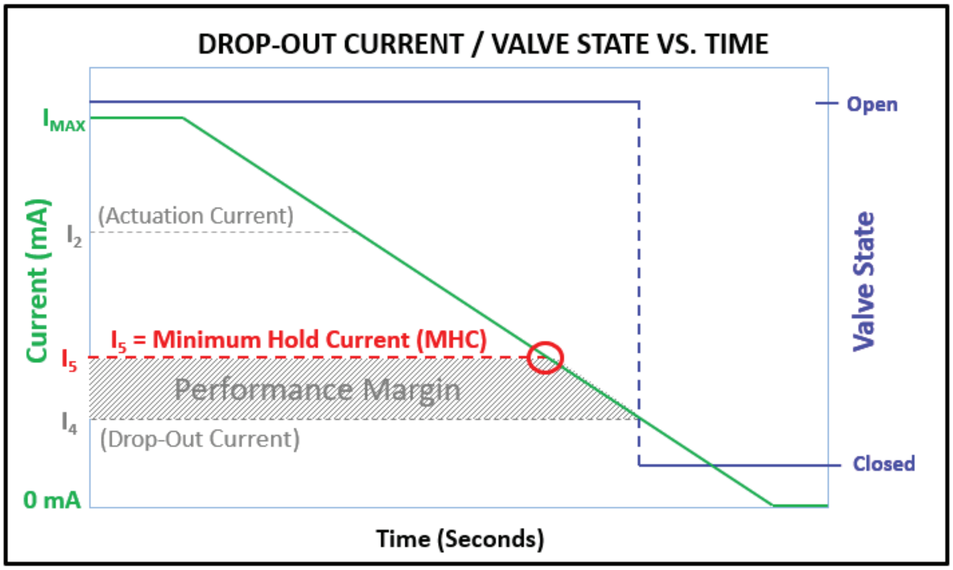
As discussed earlier, the valve will return to the nominally closed state when the power source to the coil is disconnected. Rather than suddenly disconnecting the source, if the input current is gradually decreased, the current at which the valve state change occurs can be determined. This current value is referred to as the drop-out current and is typically detected by monitoring flow rate across a normally closed orifice. Figure-12 illustrates arbitrary test results from a drop-out current test.

Figure-12



Once the actuation and drop-out current parameters are known, the end user must establish a minimum hold current (MHC) specification for the application. The MHC must include a safety buffer which accounts for drop-out current performance variations due to application parameters including, but not limited to, system vibration, ambient temperature variation, elastomer swell (due to media compatibility and/or elastomer temperature), valve function/porting, and any other application parameters which influence the drop-out current. Figure -13 illustrates an arbitrary MHC value based on the established performance margin.

Figure-13



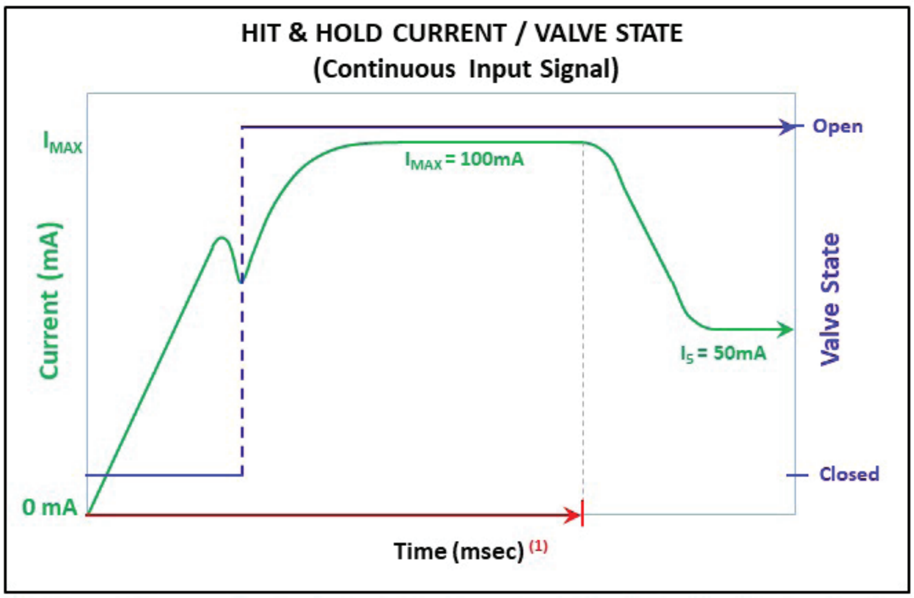
The maximum current (I_{Max}) and drop-out current (I_4) parameters illustrated in Figure -13 are not specified given that they vary with valve type and application parameters. Therefore, in order to understand the power savings potential in a hit and hold application, arbitrary values will be selected for (I_4) and (I_5) in the following example.

Efficient and Effective Direct Acting Solenoid Valve Control Capitalizing on Valve Mechanics

Let us begin by considering a 13.6 VDC / 136 Ohm valve configuration. For discussion purposes, the coil resistance will remain constant. Therefore, we are effectively ignoring any self-heating and ambient thermal effects on the coil resistance. Based on the input voltage and resistance of the valve, the (I_{Max}) value is calculated at 100mA. [I = V/R] The arbitrary values selected for (I_4) and (I_5) are 25mA, and 50mA respectively.

In this example, rated voltage is applied to the valve for a short duration, (typically less than 100 msec), to ensure actuation at 100mA, (I_{Max}). Once actuated, the input current is reduced 50mA, (I_5), and the valve remains in the actuated state.
The input current/actuation state scenario described in this example is illustrated in Figure-14 below.

Figure-14



(1) *Reference the Response Time Specification of the Valve prior to defining the duration of the (I_{Max}) signal.*

Given the arbitrary parameters above, we can now calculate and compare the power consumed by the valve at the selected current states, {(I_{Max}) and (I_5)}, using the power equation $P = I^2R$. During the initial "hit" current state, (I_{Max} = 100 mA), the effective power consumed by the coil is 1.36 Watts; this calculation is based on nominal 136 Ohm resistance. Once the current is reduced to the MHC value, (I_5=50mA), the power consumed by the valve effectively drops to 0.34 Watts. Again, this calculation is based on a constant 136 Ohm coil; there is no change or increase in resistance due internal heating of the coil. Comparing the two power states in this example, the end user has effectively reduced the continuous power consumption of the valve by 75% while maintaining the desired valve function.

It is important to understand that the pull-in response or response time of the valve will vary within the same valve family due to the differences in valve types, (2/3-way normally closed, 2/3-way normally open, distributor or directional, and universal type configurations), and variations in the magnetic gap. Therefore, in order to select a proper hit current duration, the end user should reference the response time specification of the valve prior to designing the circuit.

Now that we understand a method to characterize the actuation and drop-out parameters of the valve and have reviewed a theoretical/arbitrary example for power savings, we can now discuss optimum strategies for implementing "hit and hold" power delivery.

"It is important to understand that the voltage required to actuate the valve will vary with changes in coil temperature"

-Philip Dodge

Senior Engineer at Parker Precision Fluidics

Efficient and Effective Direct Acting Solenoid Valve Control Pulse Width Modulation Control Methodology

PWM Hold Control Methodology:

The arbitrary parameters illustrated above in Figure-14, describe two continuous 'hit' and 'hold' current values being supplied to the valve, (I_{Max}) and (I_5) respectively. In order to deliver the two separate input current levels, the power supply must be variable or the system must have two independent supplies delivering (I_{Max}) and (I_5). Given that both options are not ideal from a cost and power efficiency standpoint, the same power-saving gains can be realized by using a single/continuous DC Power supply and adding a PWM, (pulse width modulation) circuit. The following example explains this concept in greater detail.

In the prior example, (Figure-14), a continuous 100mA signal is applied to the valve prior to implementing the 50mA continuous, power saving, signal. In order to implement an equivalent PWM power saving system, the same/initial 100mA continuous 'hit' signal is required to ensure actuation of the valve. Once actuated, a 50% duty cycle PWM 'hold' signal can then be applied to obtain the equivalent power savings. Figure -15 illustrates the hit and PWM hold scenario described above.

Figure-15

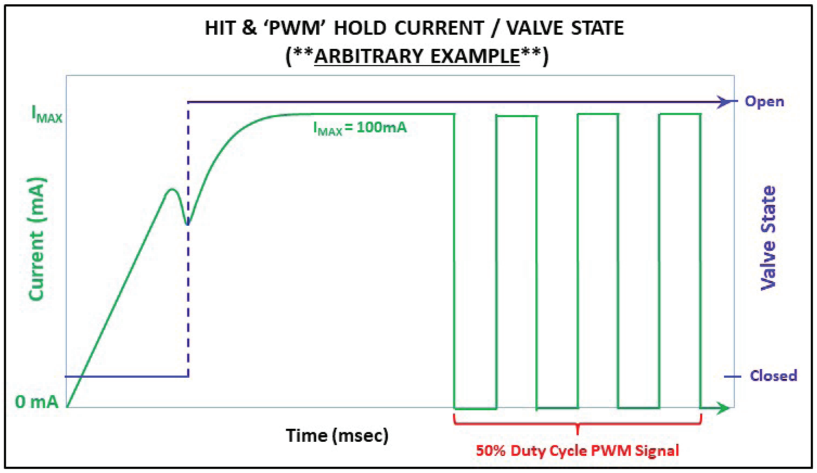
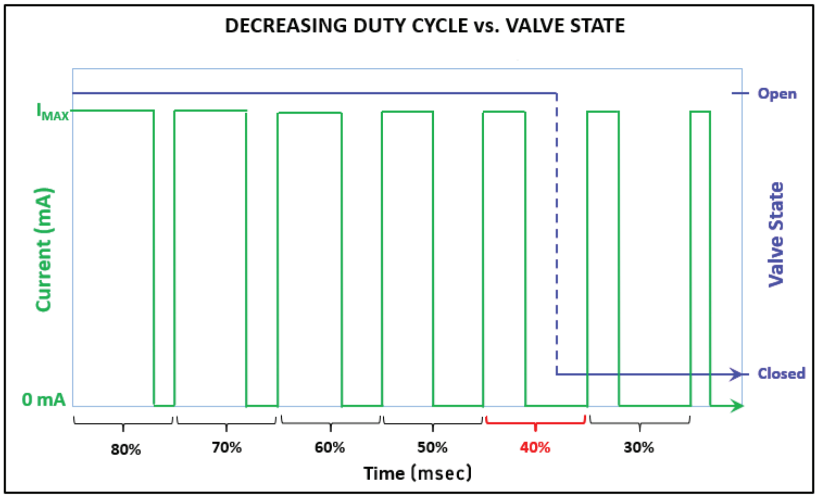


Figure-16



The 'average power' consumed in this example, (Figure-15), can then be calculated by multiplying the square of 'average current', (I_{MAX} x % duty cycle), by the coil resistance. {PAVG = $IAVG^2$ x R = (0.100s x 0.50)^2 x 136 Ω = 0.34 W} .

End users should be aware that, although the theoretical/calculated hold power is equivalent in each case, (continuous supply and PWM), the actual power consumed at drop out may vary slightly. Therefore, it is important for the end user to characterize the drop-out parameter utilizing the selected power saving method. Specific to the PWM method, this can be accomplished by simply reducing the duty cycle of the PWM hold signal until the drop-out condition is observed.

Figure-16 illustrates the output of an arbitrary duty cycle vs. valve state test. In this example, the drop-out condition is observed when the duty cycle is decreased to 40%. It should be noted that the duty cycle step sizes presented in this illustration are 'course' and are intended for explanation purposes only. In practice, the duty cycle step size changes should be no larger than 1%.

It should also be noted that the frequency of the PWM signals presented in Figures 15 and 16 is intented for instructional purpose only. Given the fast responding characteristics of a solenoid valve, the frequency of the applied PWM signal must be fast enough to prevent any mechanical oscillation of the armature; to prevent the mechanical components of the valve from chasing the oscillating electrical input signal. Specific to all solenoid valve platforms offered at Parker Precision Fluidics, PWM signals greater than 15KHz are typically recommended to prevent this condition from occurring.

Valve Design / Type Considerations:

In the 'Capitalizing on Valve Mechanics' section of this document, we touched on some of the application parameters which influence the drop-out characteristics of the valve. Of the parameters listed, (vibration, ambient temperature, elastomer compatibility, valve function/porting), valve function/porting is the

Efficient and Effective Direct Acting Solenoid Valve Control Pulse Width Modulation Control Methodology

only parameter which is tied directly to the design of the valve. This parameter is commonly referred to as 'valve type' and given the significant impact of this parameter on drop-out current, it must be considered when creating a test plan.

The solenoid valve operating principles and illustrations presented in this document are representative of a simple 2-Way/2-Position, normally closed, valve configuration. This is a common valve design, which is incorporated into this article to explain basic valve mechanics. Considering the variations in current valve designs and corresponding valve types, (2-way vs. 3-way, mono-directional vs. bi-directional flow, normally closed vs. normally open vs. distributor vs. universal), the scope of this topic is too large to address in this article. Furthermore, if the end user is unfamiliar with the valve design, mechanical requirements for the valve type, and the corresponding effects on drop-out current, it is highly recommended that they consult the technical support team at Parker Precision Fluidics. Our engineering staff can assist in identifying the appropriate test condition based on the application requirements and the selected valve design.

This white paper was written by Phil Dodge, Senior Engineer at Parker Precision Fluidics. Phil has been with Parker for 14 years.

The Parker C-Series miniature cartridge solenoid valve is available in 7 mm, 15 mm and 21 mm diameters with pressure capabilities up to 145 PSI (10 bar). These valves are ideal for light weight portable applications. Integrate a hit and hold circuit to further reduce power consumption and heat generation in handheld and portable applications.

For more information call **+1 603 595 1500** or email **ppfinfo@parker.com**

Visit **www.parker.com/precisionfluidics**

Recommendations on application design and material selection are based on available technical data and are offered as suggestions only. Each user should conduct their own tests to determine the suitability for their own use. Parker offers no express or implied warranties concerning the form, fit, or function of a product in any application.

PPF HH_WP - 001/US July 2020

Parker Hannifin Corporation
Precision Fluidics Division
26 Clinton Dr., Unit 103
Hollis, NH 03045
phone 603 595 1500
fax 603 595 8080
www.parker.com

Parker