

Sizing Pulsation Dampeners Is Critical to Effectiveness

Pressure variation is an important consideration when determining the appropriate size pulsation dampener needed for an application.

*by David McComb, Blacoh Fluid Control
Pumps & Systems, April 2014*

Positive displacement pumps effectively pump fluid at a constant average flow rate. However, because the individual pumping elements of these pumps discharge discrete quantities of fluid, the instantaneous flow rate varies in a cyclic fashion.

Pulsations are observed in the system as pressure spikes. In the positive displacement pump family, single-shoe peristaltic pumps generally create the largest pulse, followed by two-shoe peristaltic pumps. Triplex and quintuplex pumps have smooth output curves because of piston overlap. Gear pumps can have extremely small pulses, but pulsations still exist. This pulsating flow can cause operational problems and shorten equipment's service life.

To alleviate the problem, pulsation dampeners can be added to the pumping system to absorb pressure spikes and smooth fluid flow. Figure 1 shows the undampened pressure spikes from a triplex pump in green. The dampened pressure curve from the same pump with the same system settings are indicated in blue. Six pulses per revolution occur instead of the expected three. This is a result of piston overlap.

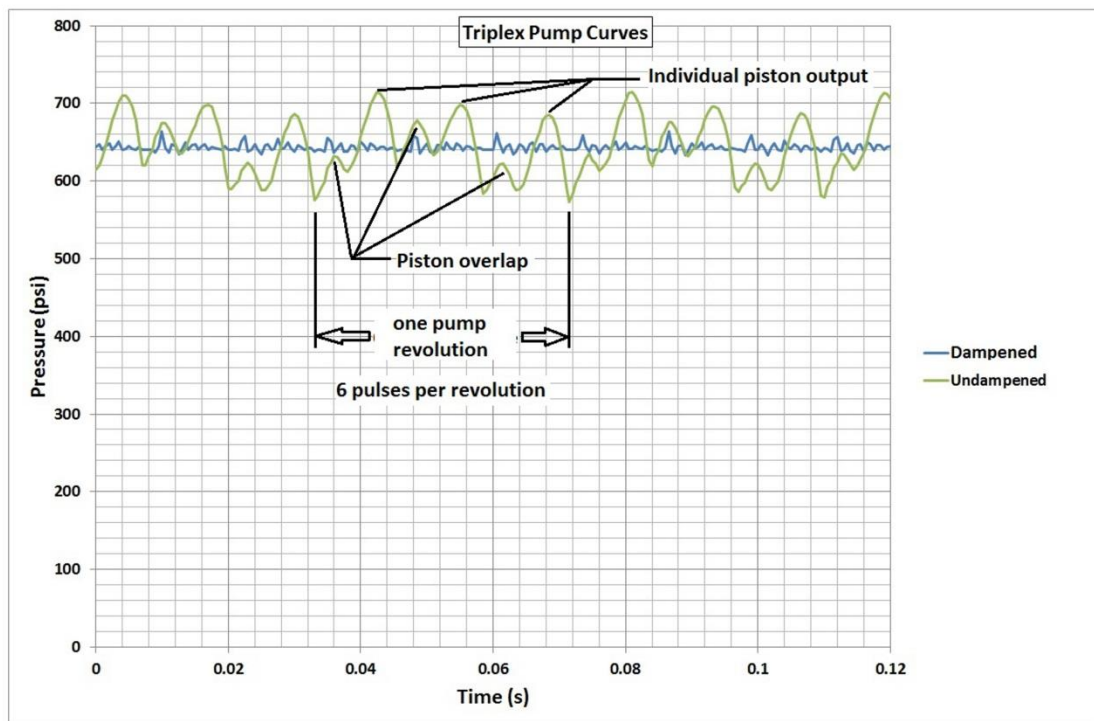


Figure 1. Triplex pump output pressure curves

Determine Adequate Size

The most common type of pulsation dampener is a hydro-pneumatic pressure vessel containing compressed air or nitrogen and a bladder—or bellows—that separate the process fluid from the gas charge. To maximize the dampening effect, pulsation dampeners should be installed as close as possible to the pump discharge with a gas charge that is slightly below the normal system pressure. More important, pulsation dampeners must be properly sized for the system.

A dampener that is undersized cannot adequately compensate for pressure and flow fluctuations. An oversized dampener will act as an accumulator, storing too much fluid. This will cause slow stabilization and a delayed response to system changes. The first step in sizing a dampener is to quantitatively define the acceptable performance.

Determine the Amount of Tolerable Pressure Variation

The specific requirements of the application and the components that make up the system are all factors that need to be considered. Once an acceptable pressure variation is defined, the unit size required for the desired performance should be determined. Engineers and designers are interested in making accurate predictions. Avoiding a problem is better than finding a way to fix it.

Calculate Pressure Fluctuations

Sizing pulsation dampeners is straightforward. However, calculating the system pressure fluctuations is more complex. Fluid discharge rates from pumps are difficult to mathematically model. For example, in Figure 1, the spikes are not even. Theoretically, they should be equal. Mathematical models must be physically tested to verify their accuracy.

Pumps with multiple heads and higher pulse frequencies can make the calculations more difficult. The distance from one output port to the next is generally not constant. This creates a shift in the piston overlap with intermittent larger and smaller pulses. Calculating the magnitude or frequency of noise pulses that can develop or resonate in a system is difficult.

Piping arrangement—such as bends, reducers and valves—combined with the opening and closing of pump discharge check valves can create noise in the fluid called pressure pulses. Because many variables must be considered, each pump type should be tested with and without a dampener. The pressure curve data can be recorded and used to find the pump's formula constant. This constant can be used in future calculations. As long as other pump models are similar to the test unit, accurately predicting the magnitude of line pressure variation with a given size dampener is possible.

Minimize Acceleration Head

The pressure in a piping system will rise sharply when a volume of fluid is added to the line. It accelerates the mass of the fluid in the piping system. This is acceleration head, and it needs to be minimized with a dampener. The effect and its impact must be considered on both the inlets and outlets of positive displacement pumps. On the inlet side, cavitation and partial filling of pump cavities can damage pump components and make the pump much louder than normal.

A non-snubbed pressure transducer can accurately measure the system's pressure spikes. A pressure transducer can react much faster than a bourdon tube gauge, and it can measure noise if the sample rate is high enough.

Bourdon tube gauges require time to equalize and can undershoot and overshoot the actual pressure depending on the magnitude and frequency of the pressure pulse. Even if the gauge could read accurately, reading a quickly moving dial is difficult. Electronically measured and recorded data can determine how the system is operating.

System noise must be considered when taking measurements because it can give higher-than-expected results. Noise in the pumping liquid can generally be ignored, but in some situations, system noise needs to be controlled. Noise can cause pressure relief valves to leak, damage sensitive components and create occupational safety hazards. Dampeners typically reduce noise, and some are specifically designed for this purpose.

Pulsation Dampener Styles

Several different styles of dampeners are available, and each has advantages and disadvantages. This article focuses on reducing the pressure pulses caused by pulsing flow. The principles and the method for calculating the appropriate size dampener for this application are the same for most dampeners.

A dampener absorbs a fluid pulse and then allows the fluid to flow back into the system between pulses. Most dampeners use a gas charge that is set slightly below the normal system pressure and is compressed by the pulse of fluid. The gas then expands when fluid is released.

Calculate Pressure Changes

Two formulas should be considered when calculating pressure changes in the gas:

If the pressure changes happen slowly, the gas temperature will have time to equalize. This is an isothermal process. The equation is:

$$P_2 = \frac{V_1 * P_1}{V_2}$$

Where P_1 and V_1 are the initial states, and P_2 and V_2 are the final states.

The other formula assumes no heat transfer from the gas to its surroundings. This is an isentropic process, and the equation is:

$$P_2 = \left(\frac{V_1}{V_2}\right)^n * P_1.$$

In this formula, n is a constant that is specific to the gas being used. For example, for air at room temperature, $n \cong 1.400$, and for nitrogen, $n \cong 1.399$.

Some heat transfer almost always occurs. The process is rarely slow enough for the gas temperature to equalize, so the actual answer will be between these two calculations. In most cases, the fluctuations are fast enough that the actual value is significantly closer to the isentropic formula. The isentropic formula gives the most conservative result. Therefore, it is the more accurate formula in most cases.

In actual practice, either formula would probably work if the pressure fluctuations are small relative to the system pressure. The pump constant that is developed would cover the inaccuracies in the formula as long as the pressure variations are similar. In this article, the isentropic formula is used.

Determine the Pump Constant

To determine the pump constant, the volume from a single pulse of the pump must first be determined. Then an initial estimate of dampener size is made, and the corresponding value of dampener volume is applied. The amount of gas in the dampener will be less than the total dampener volume, which needs to be factored into the calculation. A typical range of 80 to 90 percent of the dampener volume should be gas if the dampener is properly charged. These give an initial gas volume:

$$(V_p = \text{pulse volume})$$

$$(V_d = \text{dampener volume})$$

$$(V_{pr} = \text{percent fill})$$

$$V_1 = V_d * V_{pr}$$

The final volume is the initial gas volume minus the pulse volume:

$$V_2 = V_1 - V_p$$

The constant reduces the pulse volume to account for flow leaving the dampener while the pulse is entering. It also accounts for piston overlap, which changes the effective size of the pulse. Adding the factor to the isentropic formula and solving for the pump factor gives us the following equation:

$$f_d = \frac{V_1 * \left(1 - \left(\frac{P_1}{P_a}\right)^{\frac{1}{n}}\right)}{V_p}$$

Where:

f_d = pump factor constant

P_a = measured maximum absolute pressure

P_1 = minimum absolute line pressure

The pressure formula can be rearranged to give the desired dampener volume with given minimum and maximum pressures:

$$V_d = \frac{V_p * f_d \left(\frac{P_2}{P_1}\right)^{\frac{1}{n}}}{V_{pr} * \left(\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right)}$$

The formula can also be rearranged to give pressure variation with the pump factor and with a known dampener volume:

$$P_2 = \left(\frac{V_d * V_{pr}}{V_d * V_{pr} - V_p * f_d}\right)^n * P_1$$

Note: The formula does not account for pressure spikes that result from rapidly changing the flow rate in the piping system. These pressure spikes, also known as water hammer, can travel throughout the entire piping system and may damage pumps, piping and other fixtures. If this type of pressure transient occurs in the system, a larger dampener at the pump may be needed. Alternatively, an additional dampener at the source of the transient spike may be required.

For example, the pressure curve from an undampened, two-shoe, 2.5-inch peristaltic hose pump shows a sharp increase in flow, followed by a “no-flow” or negative flow zone. In this instance, the line has a ball valve that is creating the flow restriction for back pressure. The blue line shows the undampened pressure spikes (see Figure 2). The red line shows the pressure changes of the same pump with the same back pressure valve setting but now using a dampener. This sample dampener has an actual gas volume of 415 cubic inches, and the dampener is 90-percent gas filled. The base pressure is 14.15 psig, and the pulse is 76.9 cubic inches. If the pressure fluctuation is calculated using the isentropic pressure formula, the result is:

$$P_2 = \left[\left(\frac{(415 * 0.9)}{(415 * .09 - 76.9)}\right)^{1.4} * (14.15 + 14.7)\right] - 14.7 = 25.62 \text{ psig}$$

It is important to remember to add 14.7 psi to convert from gauge to absolute pressure, then subtract 14.7 psi again to get the final result in gauge pressure. This pump setup was tested, and the actual pressure variation was determined to be 7.38 psi. Therefore, the result is:

$$P_a = 7.38 + 14.15 = 21.53 \text{ psig}$$

Inserting the numbers into the factor formula gives:

$$f_d = \frac{415 * 0.9 * \left(1 - \left(\frac{14.15 + 14.7}{21.52 + 14.7}\right)^{\frac{1}{1.4}}\right)}{76.9} = 0.73$$

If the example above is used and it is decided that a pressure fluctuation of 15 psi would be acceptable, the formula with the previously calculated pump factor can be used to determine what size of dampener is needed.

$$V_d = \frac{76.9 * 0.73 * \left(\frac{14.15 + 14.7 + 15}{14.15 + 14.7}\right)^{\frac{1}{1.4}}}{0.9 * \left(\left(\frac{14.15 + 14.7 + 15}{14.15 + 14.7}\right)^{\frac{1}{1.4}} - 1\right)} = 222 \text{ cu in}$$

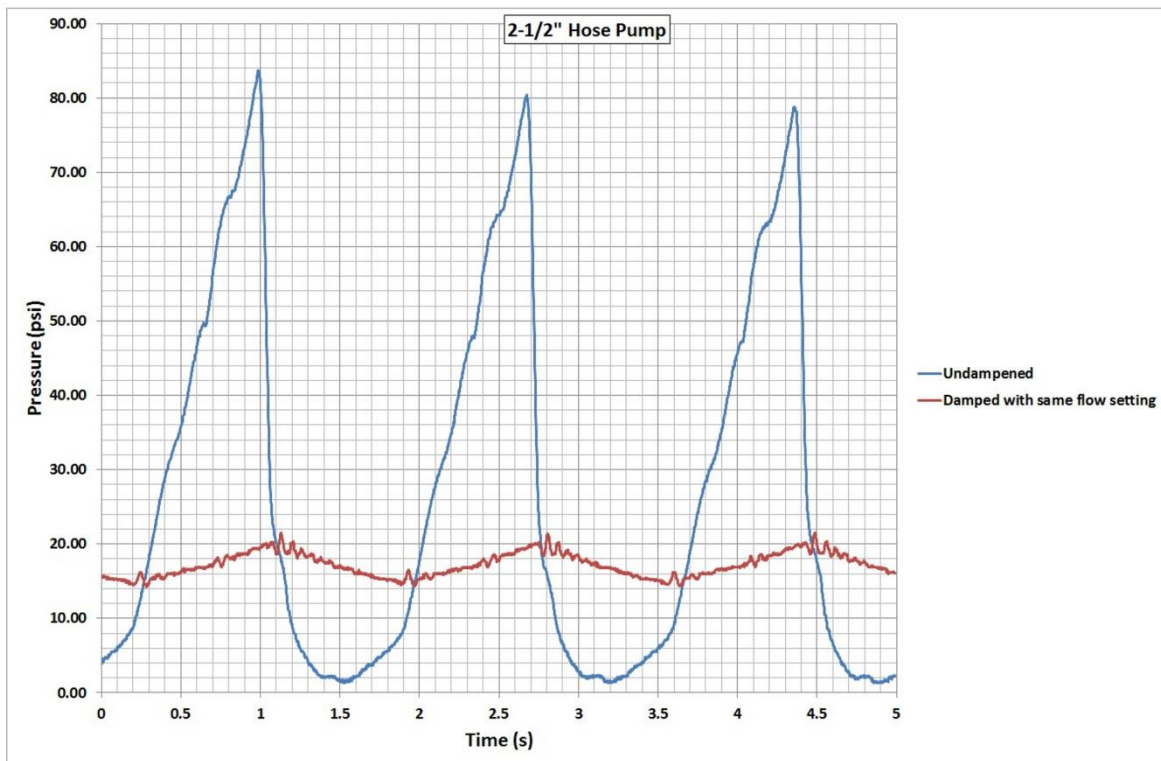


Figure 2. Peristaltic pump pressure curves

Type of pump	Factor
Single-shoe/roller hose pump	0.87
Two-shoe hose pump	0.73
Air-operated double diaphragm pump	0.19
Simplex single acting	0.60
Triplex single acting	0.13
Quadruplex single acting	0.10
Quintuplex single acting	0.06

Table 1. Pump constants

Table 1 lists some approximate pump constant factors that can be used when sizing dampeners for different pump types. These factors are approximate, and the results may vary significantly with the many variables involved.

Application 1

A triplex plunger pump doses methanol, which is metered on the discharge side. Without a dampener to control pulsations and smooth out the flow, the installed flow meters were giving inaccurate readings.

When using a triplex pump, all three chambers of the pump must stay full of fluid with no voids. Any voids or pockets can cause seal leakage, pump vibration and excess pump noise.

The solution was to install a pulsation dampener at the pump discharge to smooth the flow and remove pressure pulsations. This allowed the dosing to be more accurate. An inlet stabilizer (suction dampener) was also installed on the inlet side of the pump to act as an accumulator to keep the pump chambers filled. The inlet stabilizer also removed pulsations created by the pump on its inlet stroke. Both devices were sized based on the pump type, flow rate and operating pressure.

Application 2

During the filling of a drum with a flexible hose, an automatic valve would close and cause a water hammer effect. All the pipes leading into the system would shake until they broke loose from their supports. The solution was to install a pulsation dampener at the beginning of the flexible hose connection.

The pulsation dampener was sized based on the flow parameters and installed at the beginning of the flexible hose. When the automatic valve closed, the hose and pulsation dampener effectively absorbed a portion of the water hammer, eliminating pipe shake and improving operational safety.

Conclusion

The sizing of a pulsation dampener is critical to achieving the desired result. Finding and using the correct constant pump factor in dampener sizing is a key part of the solution. As long as the pulsation dampener is properly sized, positioned and charged, it will effectively dampen pulsations to protect equipment and keep the pressure pulses within design parameters.

David McComb is the engineering manager at Blacoh Fluid Control, a manufacturer of pulsation dampeners, surge suppressors, inlet stabilizers and other fluid control products. McComb obtained a B.S. in mechanical engineering from University of California, Riverside, and has extensive experience in project and product line management.

BLACOH Fluid Control

601 Columbia Ave, Bldg D
 Riverside, CA 92507 USA
 951.342.3100 or 800.603.7867

Sales@Blacoh.com
www.Blacoh.com