Sizing Pulsation Dampeners for Reciprocating Pumps

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The installation of properly sized pulsation dampeners minimize vessel costs while protecting the pump and piping system and improving process efficiency and accuracy.

A pulsation dampener reduces or eliminates the variations in pressure and flow produced by reciprocating pumps. In many applications, low frequency pressure waves cause problems within a given piping system and/or process. Eccentric, cam-driven pumps are probably the most commonly applied for services that require pulsation dampening (e.g., metering pumps and reciprocating power pumps).

Pulsation dampeners are produced in a variety of designs, but for our purposes we will focus only on gas-charged pulsation dampeners, which rely on a calculated volume of compressed gas, usually Nitrogen, which is alternately compressed and expanded in synchronization with the pump plunger to reduce or eliminate pressure pulsations. This gas volume is normally separated from the process fluid by a flexible membrane. Common membrane designs include elastomeric bladders, PTFE diaphragms, PTFE bellows or stainless steel bellows.

Above: Stainless steel pulsation dampener with PTFE diaphragm and flanged process connection.

Left: Cutaway of stainless steel pulsation dampener with elastomer bladder and flanged process connection.

Pressure Pulsations from a Reciprocating Pump

Pressure waves or pulses are a consequence of the alternating acceleration and deceleration of fluid velocity corresponding to the travel of the piston or plunger. The pattern and amplitude of these pulses varies with pump configuration, specifically the number and size of pistons, as well as fluid compressibility factors.

It is precisely the fluid volume above mean on the discharge cycle of each stroke, which induces these pressure pulsations into a piping system. The number of pistons offered by the pump—given that all are of identical diameter and equally phased—displace a known peak volume above mean. These constants may be influenced by fluid compressibility, but for the purpose of this explanation assume none at this point. A pulsation dampener absorbs only that portion of piston displacement above mean flow, and then stores it momentarily before discharging it during the portion of the cycle below mean flow (on the suction stroke).

A simplex pump displaces a volume of fluid above mean that is equal to about 60 percent of total displacement. A duplex pump displaces a lower fluid volume above mean, approximately half that of a simplex pump. Pumps of three or more pistons of equal diameter, stroke length and proportionally phased will always present a very small fluid volume above

mean to the piping system. A triplex pump, for example, produces about a 4 percent peak, as long as fluid compressibility factors and pump efficiencies are not at issue.

The crank angle of each of the cylinders accounts for these smaller fluid volumes. Triplex pumps are offset by 120-deg. Quadruplex pumps are set apart at 90-deg offsets; quintuplex pumps are offset 72-deg, and so on. It is the resulting overlap in pulses that yield the smaller fluid volumes above mean.

Fluid velocity gradients follow the same mechanical velocity gradients of the eccentric cam that drives the piston(s). Halfway through the piston's forward travel (discharge stroke), fluid velocity between the discharge check valve and the pulsation dampener begins to decay. The corresponding drop in pressure causes the membrane inside the dampener to expand since the internal gas pre-charge pressure is now higher than the line pressure. The (stored) fluid now being displaced by the pulsation dampener maintains velocity downstream of the dampener thereby reducing, if not eliminating, any downstream pulsations.

Note: A pulsation dampener removes pulses only from the line downstream of the dampener—not upstream. That's why it is always recommended that discharge dampeners be installed as close to pump discharge nozzles as possible. In an application of a dampener for suction stabilization (reduction of acceleration head losses), it is the velocity gradient between the supply vessel and the suction nozzle that is minimized.

Sizing Pulsation Dampeners

Let's begin by defining the pump details required to properly size a pulsation dampener. We will use these values in a sample calculation to help clarify the process.

- Triplex pump (63-mm piston diameter and 60-mm stroke length)
- Gas Pre-charge Pressure = 80 percent of system pressure
- Required Level of Dampening (LOD) = 5 percent peak-to-peak (or ±2.5 percent)
- Fluid is non-compressible

$$\text{Gas Volume Required} = \frac{\text{Pump Displacement}}{\text{\% Pre-Charge} \times \text{LOD} \times \text{Pump Constant}}$$

By multiplying the cross sectional area of the piston by the stroke length, we determine the pump displacement per stroke to be 187-mL or 0.187-l.

We recommend that the gas pre-charge pressure be set to 80 percent of system pressure. Lower pre-charge pressures may be specified elsewhere, but our experiences show that this is a low enough pressure to allow the membrane to move freely during operation while maximizing the gas volume. We will use 0.80 in the formula as the "% Pre-Charge" for 80 percent.

The level of dampening (LOD) in this example is 0.05 (5 percent peak-to-peak residual pulsations).

The result of the previous calculation is then divided by a constant. As noted previously, the constant is a function of pump configuration. We use a conservative 1.5 for simplex pumps, 2 for duplex pumps, and 7 for triplex pumps. Remember—if the fluid is compressible, then the constant may have to be adjusted downward.

Fluid volumes above mean are well within the range of these constants. The fluid pulse above mean flow from a simplex pump, for example, is about 60 percent. When we divide full stroke displacement by 1.5 the result is a conservative 67 percent. The divisor 7 that we use for triplex pumps allows for a nominal 14 percent fluid volume above mean. While 14 percent is far above the actual 4 percent produced by triplex pumps, the higher volume is an allowance for practical reasons, specifically size and nozzle limits. Otherwise, the result would be a very small dampener relative to pump size.

$$\text{Gas Volume Required} = \frac{0.187}{0.80 \times .05 \times 7} = 0.668 \text{ Liters of Gas}$$

Influences of Changing Temperatures and Pressures

Ranges of (process) temperature and pressure must be considered in any sizing calculations for pulsation dampeners. Compensations must be made for temperature variations, which affect gas density, and dynamic variations in system pressure, since sizing is based on a set pre-charge pressure.

The objective is to select a dampener that is adequately sized to handle a range of operating pressures with a single pre-charge pressure. Remember that the gas pre-charge pressure should always be based on the minimum operating pressure as the pulsation dampener will have no effect when the system pressure is below the pre-charge pressure.

In instances of either (or both) temperature and pressure variation, we compensate by multiplying the result of our original calculation by the ratio of minimum and maximum temperature and pressure extremes.

Initial calculation: 0.668 liters

Compensation: 0.668 x (Tmax / Tmin) x (Pmax / Pmin)

Changes in ambient temperature can also influence gas density, but they are generally disregarded for the purposes of pulsation dampener sizing. It is usually sufficient to make seasonal adjustments to pre-charge pressures, if necessary. It is

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recommended to use absolute values when calculating temperature and pressure (Kelvin for temperature and BarA or PSIA for pressure).

Influences of Fluid Compressibility

Some fluids are highly compressible, such as cryogenics, olefins, liquefied gases, anhydrous ammonia, etc. In these instances, the benefit of lower pulsations from multiple piston pumps may be somewhat compromised. Fluid compression occurs during the leading edge of the (eccentric) crank angle. Given sufficient pressure and a high enough compressibility factor, there may be little or no overlap of pulses at all—in which case, make adjustments and select pulsation dampeners with larger gas volumes.

Advantages of Pulsation Dampeners

By installing a properly-sized pulsation dampener, users can reduce or eliminate pipe shake, vibration and noise. The result is a continuous flow of product which is required in many metering, mixing and spraying applications. Reduced pressure pulsations minimize long-term damage to instrumentation and pump components while improving the accuracy of many flowmeters and increasing pump efficiency. **P&S**

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