SIZING PULSATION DAMPERS FOR CAM-DRIVEN, RECIPROCATING PUMPS

A pulsation damper is a device that reduces or eliminates the variations in pressure and flow produced by reciprocating pumps. In many applications it is these low frequency pressure waves that cause undesirable 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 recip (power) pumps.

These 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 in a piping system. The number of pistons offered by the pump, given that all are of identical diameter and equally phased, displace a known constant peak volume above mean. These constants may be influenced by fluid compressibility, but for the purpose of this explanation we'll assume none at this point. A pulsation damper 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% 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 and 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 4%, as long as fluid compressibility factors and pump efficiencies are not at issue.

These smaller fluid volumes are accounted for by the crank angle of each of the cylinders. Triplex pumps are offset by 120°. Quadruplex pumps are set apart at 90-degree offsets; quintuplex pumps are offset 72°, 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). Half way through the piston's forward travel (discharge stroke), fluid velocity between the discharge check valve and the pulsation damper begins to decay. The corresponding drop in pressure causes the membrane inside the damper 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 damper maintains velocity downstream of the damper thereby reducing, if not eliminating, any downstream pulsations.

Note: A pulsation damper removes pulses only from the line downstream of the damper – not upstream. That's why we always recommend that discharge damper installations to be made as close to pump discharge nozzles as possible. In an application of a damper 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 DAMPERS

We size pulsation dampers by first multiplying the displacement volume of the piston by the reciprocal of the gas pre-charge pressure. Assume a piston diameter of 63mm and a stroke length of 60mm. Piston displacement would be 187 ml. The gas pre-charge pressure is set typically at 80% of system pressure.

Convert the units to liters and multiply: 0.187(liters) x 1.25 = 0.234

Next, calculate the required gas volume by multiplying the above result times 100 / over the sum of the desired peak-to-peak residual pulsations: [(0.187 x 1.25) x (100/5)]

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, though, that 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%. When we divide full stroke displacement by 1.5 the result is a conservative 67%.

The divisor seven (7) that we use for triplex pumps allows for a nominal 14% fluid volume above mean. While 14% is far above the actual 4% produced by triplex pumps, the higher volume is an allowance we make for practical reasons, specifically size and nozzle limits. Otherwise, the result would be a very small damper relative to pump size.

A pulsation damper has to absorb these (small) volumetric peaks and limit the pressure rise to a pre-determined, maximum allowable level. To back check ourselves we'll use the target of +/- 2.5% from our example above and we'll arbitrarily select a system pressure of 64-BarG.

To find the required volume, calculate: [(0.187 x 1.25) x (100/5) / 7].

The result is 0.667 liters for a triplex pump. We'll select a 1-liter damper for this service, as this is the next available, standard size vessel. In instances like this it may be worthwhile to check and see what the resultant pulsations would be if a smaller damper were chosen. By working backwards, a half-liter damper would reduce pulsations to +/- 3.3%. If the smaller size is finally determined to be adequate, then there may be no need to opt for the larger, more expensive size.

We can check our selection by applying Boyle's Law, where:

$P_1 \times V_1 = P_2 \times V_2$.

P_1 = 64 bar
P_2 = Unknown
V_1 = 1 liter
$V_2 = V_1 - (0.187 / 7)$ Note: 7 represents the nominal 14% volumetric peak
$V_2 = (V_1 - 0.027) = 0.973$ (liters)

Check calculation:

$P_2 = [P_1 \times V_1 / V_1 - 0.027]$, or [64 / 0.973], = 65.776 Bar

(P_2) (V_2)
65.776 x 0.973 = 64 Bar

The result is 3.5 Bar (5.5% peak to peak), slightly better than our initially stated requirement at +/- 2.5% damping. Actually, calculations should be done in absolute values, but this is close enough to demonstrate our point.

INFLUENCES OF TEMPERATURE AND PRESSURE

Ranges of (process) temperature and pressure must be considered in any sizing calculations for pulsation dampers. Temperature variations affect gas density and must be compensated for. Dynamic variations in system pressure must also be accounted for, since sizing is based on a set pre-charge pressure. The objective is to select a damper that is adequately sized to handle a range of operating pressures with a single 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. Note that the final result may still lie within the originally selected damper size of 1-liter.

Initial calculation: 0.0.667 liters

Compensation: 0.667 x (Tmax / Tmin) x (Pmax / Pmin)

Changes in ambient temperature can also influence gas density. But, they're generally disregarded for the purposes of pulsation damper sizing. It is usually sufficient to make seasonal adjustments to pre-charge pressures, if necessary. Temperature and pressure calculations are recommended to be done using absolute values (°K) and BarA in extremely low pressure services.

INFLUENCES OF FLUID COMPRESSIBILITY

Some fluids are highly compressible, e.g. cryogenics, olefins, liquified 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 no overlap of pulses at all. Generally, the higher the pressure the more severe the problem. In these instances, the damper may have to be sized using graphical.