Cavitation in Hydraulic Control Valves

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How to Identify and Address Cavitation Risk - Key Points

☞ **When to check for cavitation risks:**

- If a regulating valve is operated for long durations, with a **high upstream pressure and a relatively low downstream pressure**.
- If there is **excessive noise or vibration** coming from the system.
- If valve components **on the downstream side** of the valve show **signs of wear or erosion**.

☞ **How to assess cavitation risk:**

- Calculate the cavitation conditions using the cavitation coefficient or cavitation charts provided by the manufacturer. (Find out how on page 6, section 5, "Calculating cavitation risk".
  Or
- Check for cavitation symptoms (high-frequency noise, vibrations…).

☞ **What to do if cavitation exists or is expected to occur:**

- **Modify system design**:
  - If possible, favor the use of control functions which fully open the valve, rather than regulating control functions.
  - Reduce pressure drop across the valve by:
    - Using **multiple valves in series**.
    - Installing an **orifice plate** or a fixed resistance (for example, tappers) to reduce the pressure difference (ΔP) across the valve.
- **Choose anti-cavitation valves or trim options, such as**:
  - **Anti-cavitation cages** (for example, DOROT's "F" trim).
  - **Air suction** solutions (available from Aquestia for specific models).
- **Select durable materials**:
  - **Stainless steel** to resist erosion.
  - **Special coatings** to reduce damage from implosions.

Got any questions?

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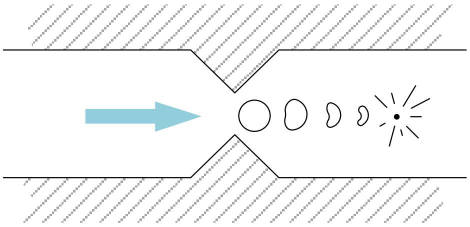
A Deeper Dive

1. Introduction

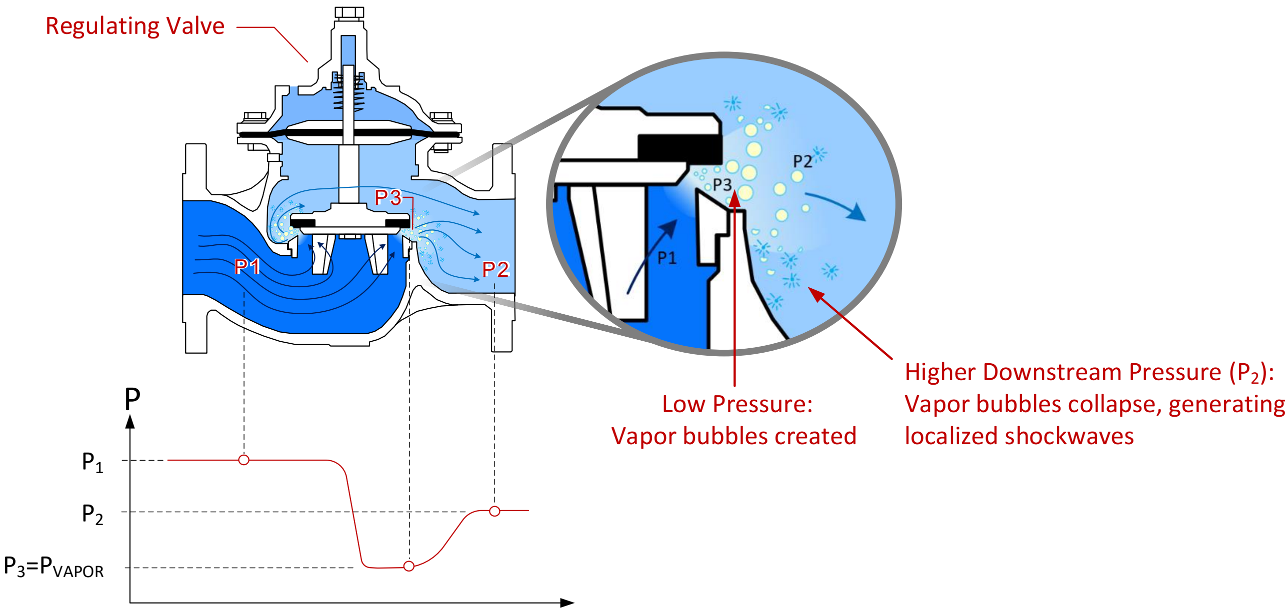
Cavitation is a common, yet potentially damaging, phenomenon in fluid system control valves. It occurs when localized pressure drops below the vapor pressure of the liquid, forming vapor bubbles. These bubbles collapse violently, often causing severe damage to valve components and reducing both performance and service life. For this reason, understanding the causes and consequences of cavitation is critical for engineers and system designers. In this article, we explore how cavitation develops, its effects on valves, how to assess the risk of occurrence, and the methods available to prevent it.



2. Understanding Cavitation

In a throttled regulating valve, fluid velocity in the vena-contracta (the narrowest flow passage between the seal and the seat) can be extremely high. This extreme velocity causes a localized pressure drop, potentially reaching as low as vapor pressure - a sub atmospheric pressure value at which water boils and vapor bubbles form. These vapor cavities travel downstream, where velocity decreases and pressure rise. As a result, the vapor bubbles collapse and implode, generating localized shock waves that can cause various effects, including:

- **Noise and vibrations:** Audible, often high-pitched sounds caused by rapid bubble implosions.
- **Flow disruption:** Vapor formation can choke fluid flow, reducing system efficiency.
- **Material erosion:** Repeated implosions erode valve components, potentially causing failure.



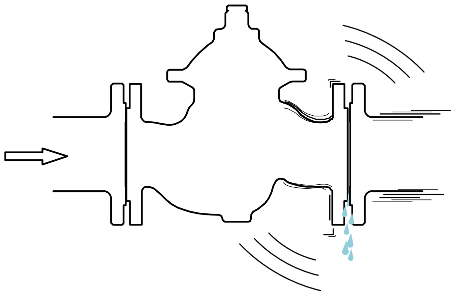
3. Issues Associated with Cavitation

Noise

When the vapor bubbles collapse, noise is emitted across a broad frequency spectrum. Several factors influence noise levels, including the bubble collapse rate, fluid properties, and valve geometry. It travels through building walls and connected pipelines, disturbing residents and workers. However, it is more than just a nuisance - it signals the release of destructive energy within the valve.

Vibrations

Produced by the uneven forces generated during the collapse of vapor bubbles, vibrations can propagate through the valve, piping, and supporting structures, potentially leading to mechanical fatigue, loosening of connections, and long-term structural damage. The severity of vibrations depends on the intensity of the cavitation, the system's structural rigidity, and resonance effects within the piping network.



Impact on Hydraulic Performance

In addition to the typical effects discussed above, cavitation can significantly alter fluid dynamics:

- **Choked Flow:** Limits the maximum achievable flow rate, regardless of increased pressure differentials.
- **Pressure Recovery Issues:** Reduces valve efficiency, due to disturbed flow patterns.

Cavitation Erosion

Cavitation causes potholes to form on the downstream side of the throttled valve's body and internal trim. The erosion happens in phases. In the **incubation phase**, material deformation begins, but no measurable weight loss occurs. This is followed by the **acceleration phase**, in which repeated stress cycles lead to rapid material loss. Prolonged severe cavitation can lead to material loss that is significant enough to cause cavities that penetrate the valve body or damage internal components, potentially impairing valve functionality. Material properties like hardness, ductility, and surface finish significantly impact erosion rates.

4. Cavitation Intensity

Cavitation is categorized into three main levels: **Incipient Cavitation**, **Critical Cavitation**, and **Choking Cavitation**.

- **Incipient Cavitation** occurs when small vapor cavities first begin to form. At this stage, the energy released during bubble collapse is too weak to cause system damage, though low-intensity noise may be noticeable.
- **Critical Cavitation** is the level at which damage starts to accumulate in valve components. Louder noise and noticeable vibrations are present. Ideally, operators should avoid crossing this threshold. However, if the required system function demands operation under these conditions, mitigation strategies should be considered. A key parameter here is the **critical cavitation coefficient (σ_c)**, which relates operating pressures to the point where critical cavitation begins. Cavitation damage can be expected when the cavitation coefficient ratio (see below section 5: Calculating Cavitation Risk) falls below this critical threshold.
- **Choking Cavitation** is the most severe form of cavitation. Operating under these conditions leads to rapid damage—sometimes within days—accompanied by loud, rumbling noises and severe vibrations.

The severity of cavitation is influenced by factors such as:

- **The cavitation coefficient** (see below section 5: Calculating Cavitation Risk): This value is calculated using the actual pressure conditions, upstream and downstream of the valve location, as it operates. A higher upstream to downstream pressure ratio increases bubble formation and collapse activity, and with it the risk of cavitation damage.
- **Fluid properties:** Characteristics like viscosity, density, and dissolved gas content significantly affect cavitation behavior.
- **Valve geometry:** Designs that cause sharp pressure drops are more susceptible to cavitation.

5. Calculating Cavitation Risk

The basic calculation for predicting cavitation damage is:

$$(1)\quad \sigma = \frac{P_1 + A}{P_1 - P_2}$$

where:

σ : the cavitation coefficient (a factor of the specific operating conditions)

A :

Pressure Units	'A' value
mwc	9
bar	0.9
psi	13

P_1 : upstream pressure

P_2 : downstream pressure

(2) Cavitation damage occurs when: $\sigma < \sigma_C$

where:

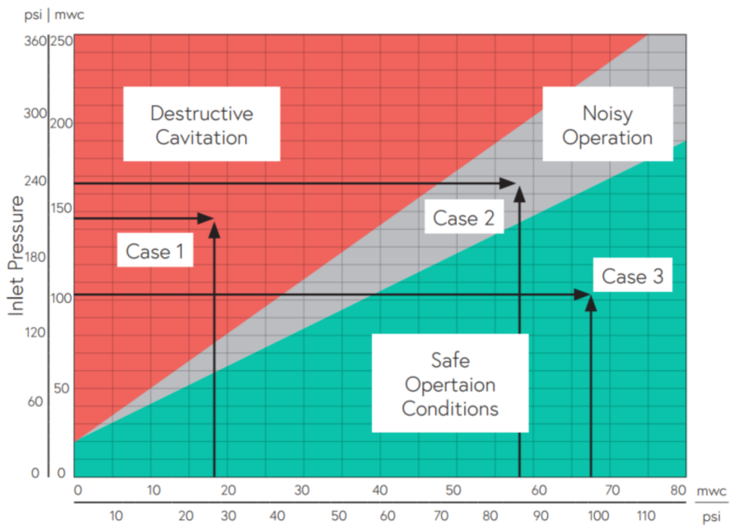
σ_c : the critical cavitation coefficient of the specific valve model

Typical σ_c (Critical Cavitation Coefficient) of HCVs:

Valve Model	σ_c (Critical Cavitation Coefficient)
DOROT S300	1.45
Typical Globe HCVs	1.5-1.55
DOROT S500	
DOROT S100	1.55
Typical Y pattern HCV	

Cavitation resistance, represented by the σ_C cavitation coefficient,
can be tested using computerized flow simulations. However, validating these results requires specialized equipment and specific conditions. Such conditions are available in select academic laboratories, like those at Delft University of Technology and the University of Utah, where DOROT control valves have been tested.

An alternative method to assess cavitation risk is through a graphical representation of the above calculations, commonly provided by the valve manufacturer. Below is the cavitation chart for DOROT S300 control valves:



! NOTE:

Cavitation damage accumulates over time, typically requiring several months of severe conditions to affect system integrity. If cavitation occurs only intermittently—lasting seconds, minutes, or even hours annually—while the valve otherwise operates safely, no special action need be taken. Example: a Safety, Quick-Acting Pressure Relief Valve (DOROT function code 'QR') remains closed most of the time and, when open, experiences extreme cavitation for only a few minutes before closing again. Such brief exposure is insufficient for significant damage to accumulate over the valve's lifespan.

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6. Cavitation Resistance

Materials with high resilience to cavitation typically possess:

- **High hardness:** Resistance to surface deformation.
- **Toughness:** Shock absorbance without fracturing.
- **Corrosion resistance:** Resistance to chemical degradation in conjunction with cavitation.

Flow-path design can also contribute to cavitation resistance, by directing the vapor bubbles away from the valve body and internals, and toward the center of the flow stream, where it causes no damage.

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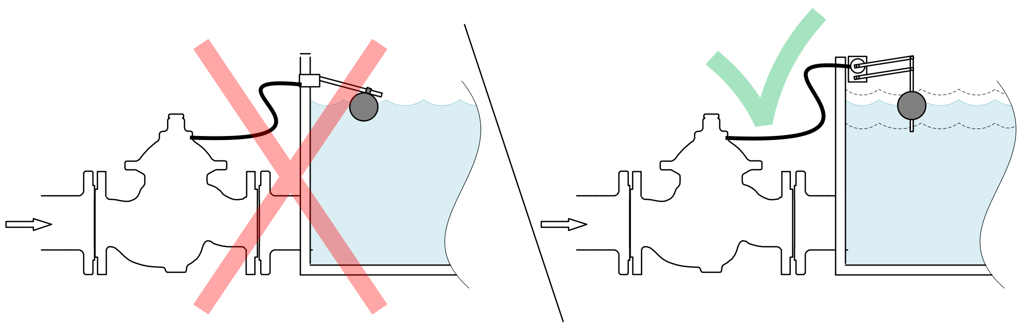
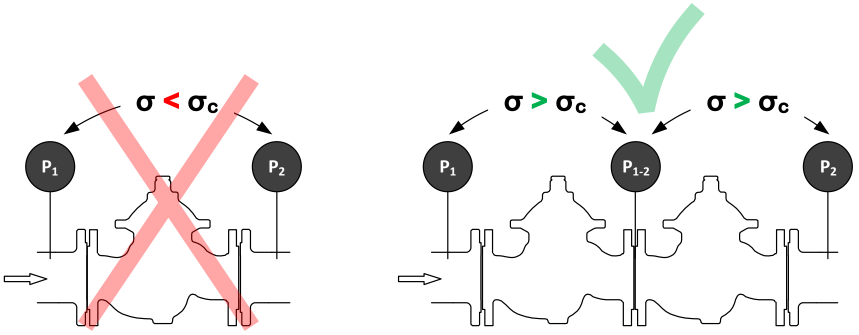
7. Avoiding Cavitation

Strategies to prevent cavitation include:

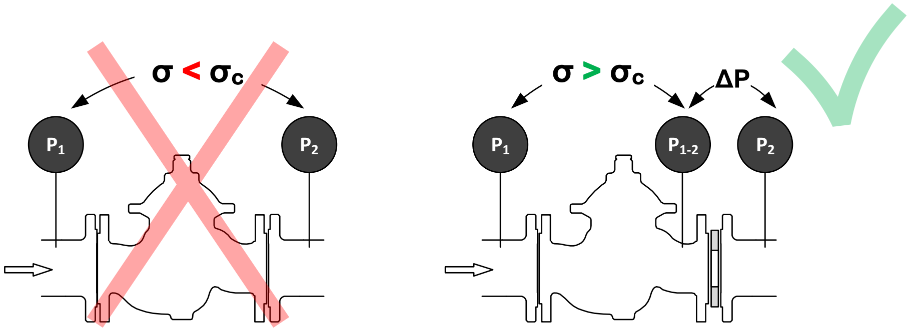
- **Selecting a control function that avoids high ΔP across the valve:** Choose fully-open valve operation, where throttling can be avoided. For example, avoid using modulating level control (functions codes 'FL' or 'AL2W') and instead use differential level control (fully open at a low level to fill the tank; closed drip tight when the level reaches a maximal allowed value) such as functions 'FLDI', 'FLEL' or 'AL3W'.



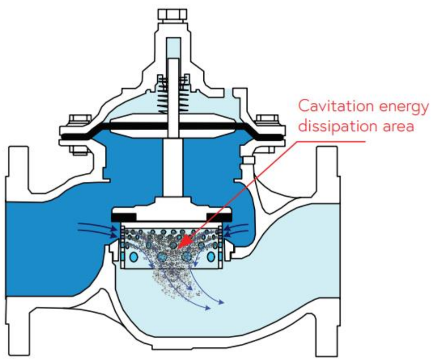
- **Employing pressure differential management:** Keep operating pressure ratios below critical cavitation thresholds ($\sigma > \sigma_c$). This can be done by:
    - **Installing two or more valves in series**, with each valve controlling part of the required ΔP across the system. For example, two or more Pressure Sustaining/Relief valves (function code 'PS[R]') can be installed to ensure that they don't operate under cavitation conditions.



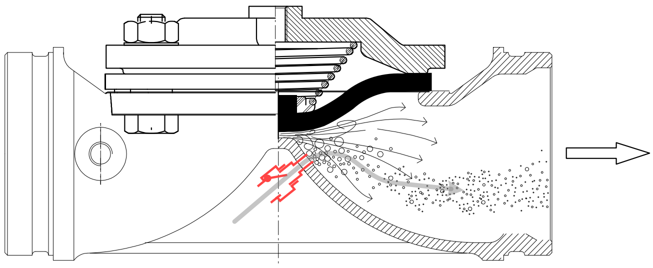
- **Installing an orifice plate in series with the control valve:** A lower cost option than the above, this can be deployed if the flow through the system is regulated to a fixed valve or varies within a limited range. A typical example would be regulating flow into a low tank or reservoir using control functions such as 'FLDI/FR', 'FLEL/FR' or 'AL3W/FR'. In such a case, the typical supply pressure may be high, while the downstream pressure is very low. A downstream orifice can be used to create a high ΔP at the regulated flow, creating a higher back-pressure for the valve (thus reducing the ΔP across the valve).



- **Configuring the valve:**
  In cases where cavitation is unavoidable, selecting valves designed to withstand cavitation effects can prolong service life.
  - **Trim Design**: Use anti-cavitation cages and optimized flow-path trims to control pressure drops. A good example of this is the DOROT Anti-cavitation trim design (model code '30F'). The unique design of this trim causes the vapor bubbles to implode in the flow, far from the valve internals, dramatically reducing the risk of cavitation damage.



  - **Anti-Cavitation Air-Suction:** This is a unique solution provided as an optional feature in DOROT S100 control valves. Special air-suction devices allow jets of atmospheric air to enter the low-pressure area in the vena-contracta, thus preventing the pressure from dropping below the vapor pressure, thereby preventing vapor bubbles from forming. The air bubbles do not implode, and serve as shock absorbers, further limiting the risk of cavitation damage.



- **Selecting valves made from resistant materials:**

  While choosing valve construction materials - such as stainless steel - that resist both erosion and corrosion will not prevent cavitation altogether, it can extend the time before critical damage occurs. This approach is suitable in systems where cavitation conditions exist only during part of the valve's operation time.

  In cases where cavitation is unavoidable, selecting valves specifically designed to withstand cavitation effects can significantly prolong service life.

Bonus Advice: Reduce noise caused by tank filling

Strategies to mitigate noise and vibration issues include:

• **Using flexible connections:**

High-frequency vibrations traveling through the pipe can radiate as noise from the pipe walls. Use a flexible or soft connection between the valve body and the downstream pipe (see 'A' in the sketch below) to help absorb vibrations and noise, preventing their transmission into the piping system.

• **Employing structural isolation:**

Apply flexible or soft isolation at points where pipes connect to the building structure (see 'B') or pass through walls (see 'C') to minimize noise transfer.

Although not related to cavitation, tank filling is a common source of substantial noise in residential buildings. To minimize this:

• **Prevent splashing:**

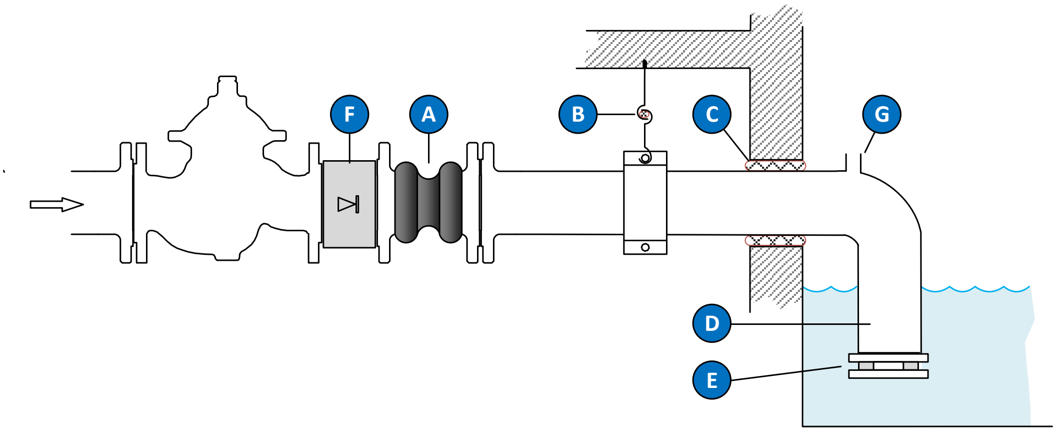
Avoid allowing the filling pipe to discharge above the water surface. Instead, extend the pipe into the tank (see 'D').

• **Use an orifice plate correctly:**

If an orifice plate is installed, place it at the open end of the pipe, inside the tank (see 'E').

• **Prevent siphonage:**

- Add a check valve (see 'F') in series with the level control valve, or ensure the control function includes a check feature.
- If the pipe enters from the top of the tank, install a small-diameter breather (see 'G') at a high point above the water level.



8. Conclusion

Control valves operating with high upstream pressure and relatively low downstream pressure may be subjected to damaging cavitation, a phenomenon that can negatively impact control valves and overall system performance. By understanding its causes, effects, and mitigation strategies, engineers can design and operate systems more effectively, reducing the associated risks.

For an assessment and help selecting the appropriate mitigation method for your specific case, please contact Aquestia's Technical Support: https://www.aquestia.com/contact-us/