Instructions to Voters/Comments on API 520 Part II Ballot – "Annex C - Speed of Sound"

- Your comments should be limited to the **red-lines portions of the ballot only.**
- If you are voting negative, please indicate which of your comment or comments are the reason for your negative vote. API's Balloting system will categorize all of your comments as Negative.
- Don't worry about formatting issues, particularly with the equations since these are a mess. These will be fixed during final editing.

Thanks to Georges Melhem and his work group for their efforts.

Phil Henry
TF520 Chairman

Sizing, Selection, and Installation of Pressure-relieving Devices

Part II—Installation

API STANDARD 520, PART II
SEVENTH EDITION, OCTOBER 2020

American
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Annex C
(informative)

PRV Acoustic Interaction

C.1 General

This annex describes a method for assessing one acoustic interaction phenomenon with direct spring-loaded PRVs as described in 7.2.4. This technical area is still being researched, so future changes are possible. PRV instability may occur even though this criterion of inlet length limit is satisfied [14] [15].

C.2 Applicability of this Method

PRV and inlet line acoustic interaction depends on the fluid properties, type of PRV, rate of pressurization, speed of PRV opening, and the length of the PRV inlet piping (see 7.2.4 for description). The magnitude of the effect of the acoustic interaction is highly dependent on how quickly the PRV opens (or closes) and the speed of sound in the fluid.

Acoustic line length limits or acoustic analysis can be applied to direct spring-loaded valves in any fluid service.

PRV chatter can occur while relieving vapor, liquid, or two-phase fluids. It is important to note that PRV damage is more likely to occur in liquid service due to the large magnitude of the water hammer pressure waves propagated upstream during rapid valve closure (full or partial), i.e. during chatter or during flutter. Damage can still occur in vapor/two-phase service due to potentially large mechanical forces caused by the rapid valve opening and closing. This may be especially true for large valves and/or for valves in high-pressure service.

Acoustic analysis may not be warranted for the following services because these are lower-risk applications.

a) any pilot-operated PRV with a remote sense line connected to the protected equipment, because the valve's opening response will be independent of the pressure in the PRV inlet;

b) any modulating pilot-operated relief valve, because the response speed of a modulating pilot valve is sufficiently slow to allow for the pressure wave to reflect back in time, which would keep the PRV open;

c) thermal relief valves where the relief load is very small and transient.

C.3 PRV Inlet Acoustic Line Length Limits

If the physical length of the PRV inlet line exceeds the acoustic length as calculated below, instability may occur.

$$L_a = \frac{ct_o}{2} \qquad \text{(C.1)}$$

where

L_a is the inlet line acoustic length in ft [m];

c is the acoustic velocity (speed of sound in the fluid) in ft/s [m/s];

t_o is the opening time for the PRV in seconds.

This is an active area of research, and this simple criterion may not address all forms of instability. Other forms of acoustic interactions with the PRV may require shorter line length criteria (see referenced publications in 7.2.4).

For example, the PRV inlet line length should not exceed 30 ft (9.1 m) for a PRV in liquid service with an opening time of 20 ms where the speed of sound in the liquid is 3000 ft/s (914 m/s).

The PRV inlet line length should be measured from the protected system to the PRV inlet flange, including any process piping used during normal operation that forms part of the pressure relief path to the PRV. Alternatively, the inlet line length may be measured from the PRV inlet flange to the first significant acoustic reflection point. An acoustic reflection point in the piping should be abrupt and have sufficient capacitance to absorb the rarefaction wave. This is described in several texts that cover acoustics, such as *Fundamental of Acoustics*, 4th edition [17]. Neither an elbow nor a series of reducers are acoustical reflection points. An example of an acoustic reflection point is an abrupt cross-sectional area change where the upstream piping cross-sectional area is approximately 10 or more times larger than the downstream piping cross-sectional area, and the length of the upstream piping is more than 20 times the diameter of the downstream piping (e.g. 3-in.-diameter pipe connected to a 12-in.-diameter pipe that is greater than 80 in. long). In this example, calculations show that this results in about 98 % of the rarefaction wave being absorbed.

C.4 Speed of Sound

C.4.1 Generalized Equation

The speed of sound is the square root of the partial derivative of pressure with respect to density at constant entropy. The speed of sound characterizes the propagation of an infinitesimal pressure wave in a fluid that is unconfined:

$$c_s = \sqrt{\left(\frac{\partial P}{\partial \rho}\right)_s} = \sqrt{\frac{1}{k_T \rho}}\sqrt{\left(\frac{c_p}{c_v}\right)} = c_T\sqrt{\left(\frac{c_p}{c_v}\right)}$$

~~$c = \sqrt{\left(\frac{\partial P}{\partial p}\right)_s}$~~

~~The isentropic bulk modulus may be used to replace the partial derivative, so the speed of sound in the medium may be calculated for liquids as:~~

~~in USC units:~~

~~$c = 8.62\left(\frac{K_S}{S}\right)^{0.5}$~~

~~in SI units:~~

~~$c = \left(\frac{K_S}{S}\right)^{0.5}$~~

~~where~~

~~K_S is the isentropic bulk modulus of elasticity for the fluid in psi (kPa) (can be calculated from the isothermal bulk modulus of elasticity for the fluid by multiplying by the specific heat ratio, C_p /C_v, for the fluid);~~

~~S is the specific gravity of fluid at relieving conditions.~~

where

c_s is the speed of sound at constant entropy in [m/s]

c_T is the isothermal speed of sound in [m/s]

P is the system pressure in [Pascals]

ρ is the fluid density in [kg/m^3]

c_p is the fluid specific heat capacity at constant pressure in [J/kg/K]

c_v is the fluid specific heat capacity at constant volume in [J/kg/K]

k_T is the fluid isothermal compressibility in [/Pa]

The general equation presented above applies to a pure component fluid and to mixtures alike. The density of a homogenous two-phase mixture can be expressed as a function of the volumetric void or vapor fraction:

$$\rho_m = \alpha\rho_g + (1-\alpha)\rho_l$$

where

ρ_m is the homogenous two-phase mixture density in [kg/m^3]

ρ_l is the liquid density in [kg/m^3]

ρ_g is the vapor or gas density in [kg/m^3]

α is the volumetric void or vapor fraction

C.4.2 Liquid Speed of Sound

Accurate values of the liquid speed of sound require accurate values of the isothermal compressibility, k_T. The liquid isothermal compressibility can be determined from a suitable equation of state or by measurement for single and/or multicomponent liquid mixtures.

Be aware that values from process simulators for the speed of sound in a ~~fluid~~ liquid, in particular a multicomponent ~~fluid~~ liquid, can be highly variable depending on how the process simulator does the calculation. If a simulator is used to estimate the speed of sound, the method for calculation should be validated against measured speed-of-sound values for common fluids. The user may want to do a sensitivity study to cover a range of values for critical applications.

C.4.3 Multi-phase Flow Speed of Sound

The isentropic two-phase mixture speed of sound can be calculated by differentiating pressure with respect to mixture density at constant entropy [36]):

$$c_{m,s} = \sqrt{\frac{1}{\dfrac{\alpha}{c_{g,s}^2} + \dfrac{1-\alpha}{c_{l,s}^2} + \left(\rho_g - \rho_l\right)\left[\dfrac{\partial\alpha}{\partial P}\right]_s}}$$

where

$c_{m,s}$ is the mixture speed of sound at constant entropy in [m/s]

$c_{g,s}$ is the gas or vapor speed of sound at constant entropy in [m/s]

$c_{l,s}$ is the liquid speed of sound at constant entropy in [m/s]

For flashing flows, the isentropic change of void fraction with respect to pressure is always negative and has a significant impact on the two-phase speed of sound. As a result, the two-phase speed of sound for flashing mixtures can be as low as 15 m/s. For frozen flow, the void fraction is constant and the change of void fraction with respect to pressure is 0. Therefore, the mixture speed of sound for frozen flow will always be higher than that for a flashing mixture.

The speed of sound in a ~~fluid~~ liquid is affected by the hoop elasticity of the piping [32, 36]. The higher the pipe elasticity, the lower the speed of sound is in the fluid, which results in a reduced acoustic line length. For typical steel petrochemical piping, the piping materials and wall thicknesses result in negligible increases in the speed of sound. If, however, the piping material has high elasticity, this effect should be considered.

C.5 Speed of PRV Opening

Spring-loaded PRVs can have very rapid opening times (measured in ms) depending on the valve type, trim, size, set pressure, fluid phase, and pressurization rate. Representative values may be obtained from the PRV manufacturer. In general, measured opening and closing times for PRVs range from 20 to 50 ms depending on the size of the valve. Several references [22][31] are available that provide guidance on how to calculate opening/closing times if this data is not available from the manufacturer. The user may want to do a sensitivity study to cover a range of values for critical applications.

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