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Instructions to Voters/Comments on API 520 Part II Ballot 2 – "Annex C – Critical Line Length"

- This is the 2nd Ballot covering Action Item 2016-11. During ballot comment review, it was decided to send the item back to the work group for resolution of several key issues.
- This ballot is a "start-over". Red-lines below reflect changes to the current 7th Edition. 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.

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

Phil Henry
TF520 Chairman

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Sizing, Selection, and Installation of Pressure-relieving Devices

Part II—Installation

API STANDARD 520, PART II

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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

Acoustic interaction leading to pressure relief valve instability can occur when the physical inlet line length approaches and exceeds a critical length value. The critical length is associated with dynamic coupling between the relief valve and the acoustic response of the fluid in the inlet piping. As the inlet piping length increases, the flowing fluid column can interact with the valve dynamically and lead to unstable operation.[12][14][30]. If the physical length of the PRV inlet line exceeds the acoustic length as calculated below, instability may occur. The critical line length is normally established as:

$$L_a = \frac{c t_o}{2} \quad \text{(C.1)}$$

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$$L_{crit} = \frac{ct_o}{2} \approx \frac{c}{4f_n} \tag{C.1}$$

where

L_{crit} is the upper piping ~~inlet line acoustic~~ length predicted to maintain stable valve operation in ft [m];

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

t_o is the opening time for the PRV in seconds~~.~~ and is approximately equal to $1/2f_n$;

f_n damped natural frequency of the relief valve moving system (disc, disk holder, spindle, spring, spring retainer, and any other components associated with mass in motion) in Hz [Hz].

The simplified expression by Izuchi defines a critical inlet line length based on the interaction between the quarter-wave acoustic mode of the fluid contained in the inlet piping and the dynamic response of the relief valve.[14][15] When this acoustic response of the piping couples with the natural frequency of the relief valve, instability may occur. This leads to an expression of the overall effective frequency of the relief valve:

$$f_{n,eff} = f_n \sqrt{\frac{x + x_0}{x} + \vartheta} \tag{C.2}$$

where

$f_{n,eff}$ effective natural frequency of the valve in the system in Hz [Hz];

x is the valve lift at the operating point being evaluated in [m];

x_o initial spring compression (spring preload) corresponding to zero lift in [m];

ϑ dimensionless correction factor representing the effect of flow forces on the valve restoring force and overall system stiffness, defined as $\left[1 - \beta \frac{df}{dz}\right]$ in the original Izuchi formulation;

The following formulation has been shown to provide a reasonable screening-level approximation for relief devices designed in accordance with API 526. Incorporating correlations of x_o developed by Grolmes and Melhem[33][40] to estimate the initial spring compression term using the effective moving mass and spring constants from a limited population of analyzed relief valves, the above C.2 expression can be simplified as follows:

$$f_{n,eff} \approx f_n \sqrt{\frac{1}{1 + \left(\frac{P_{Set}}{P_{full}}\right)\left(\frac{x_{capacity}}{x}\right) + \vartheta}} \tag{C.3}$$

where

P_{set}/P_{full} the ratio of the set pressure to the full-lift pressure at certified capacity, dimensionless;

$x_{capacity}$ is the valve full lift at the certified capacity in [m];

It is been found that the contribution of ϑ can be considered to have negligible impact on the value of the inlet

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line critical length and stability at or near full certified capacity lift conditions thus simplifying the previous C.3 equation at typical 10% overpressure for API 526 relief valves aligning with experimental test results using air as the test fluid: [14][20][30][37][38][39]

$$L_{crit} \approx \frac{c}{5.53 f_n} \approx \frac{c t_o}{2.76} \approx 0.362\, c t_o \qquad where\ t_o \approx \frac{1}{2 f_n} \qquad \text{(C.4)}$$

For conditions of partial lifts, such as the lift at required capacity, an estimate of the critical line length can be calculated using Equation C.3 for a more detailed approach including additional approximations suggested in available literature[40]. The critical line length expression presented in Equation C.1 is intended for simple inlet line geometries (constant diameter). For complex inlet line geometries, and/or for installations where the inlet line length exceeds the estimated simple critical line length using Equations C.1, C.3, or C.4, a one-dimensional dynamic analysis is recommended to evaluate PRV stability.

This acoustic interaction 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). Uncertainties with acoustic interaction calculations suggest staying at least 20% below the estimated critical value as determined in this Annex. Additional guidance on how to use the critical line length criteria with the force balance criteria for pressure relief valve stability screening is available in the open literature[12][14][30][33].

~~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:

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

where

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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 liquid, in particular a multicomponent 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]):

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

where

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

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$c_{g,s}$ 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 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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