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Control Valve Aerodynamic Noise Prediction

ANSI/ISA-S75.17 — Control Valve Aerodynamic Noise Prediction

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Preface

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Contents

1 Scope

This standard establishes a method to predict the noise generated in a control valve of standard design by the flow of compressible fluid and the resulting noise outside of the pipe and downstream of the valve. The transmission loss (T_L) equations are based on a rigorous analysis of the interaction between the sound waves that exist in the pipe and the many coincidence frequencies in the pipe wall. Commercial pipe specifications allow a relatively wide tolerance in pipe wall thickness. This limits the value of the very complicated mathematical methods required for a rigorous analysis; calculations prove that a simplified expression is justified.

The equations in this standard make use of the valve sizing factors defined in ANSI/ISA-S75.01 and ANSI/ISA-S75.02.

This method was developed from the fundamental principles of acoustics, fluid mechanics, and mechanics.

2 Limitations

The method presented in this standard considers only single-phase dry gases and vapors; it is based on the perfect gas laws. Predictions are limited at this time to a downstream maximum velocity of Mach 0.3. Ideal straight metal pipe is assumed downstream. Uncertainties become greater as the fluid behaves less perfectly for extreme temperatures and for downstream pressures far different from atmospheric or if near the critical point.

The method can be used with all conventional control valve styles including: globe, butterfly, cage type (but not with low-noise trim), and modified ball types. Specifically excluded are multistage proprietary low-noise valves and full-bore ball valves.

This standard addresses only aerodynamic noise and does not consider any noise generated by mechanical vibrations, unstable flow patterns, and other unpredictable behavior.

In the typical control valve, little noise travels through the wall of the control valve. The noise of interest is that which travels downstream of the valve inside the pipe and then escapes through the wall of the pipe to be measured typically at 1 meter (3 feet) downstream of the valve body and 1 meter (3 feet) away from the outside surface of the pipe.

The majority of the test data available to validate the method is from air at moderate downstream pressures and temperatures; however, it is believed that the method is generally applicable for other gases and vapors and at higher pressures. The equations include terms that account for fluid density and ratios of specific heat.

3 Nomenclature

Symbol	Description	Customary US Units	SI Units
c_2	Speed of sound, downstream	ft/s	m/s
C_V	Valve flow coefficient	$gpm/\sqrt{psid}$	[1]
c_{vc}	Speed of sound at the vena contracta at subsonic flow conditions	ft/s	m/s
c_{vcc}	Speed of sound at the vena contracta at sonic flow conditions	ft/s	m/s
D_j	Diameter of jet	ft	m
D_i	Diameter, internal, pipe [2]	ft	m
F_d	Modifier, valve style	dimensionless	dimensionless
F_L	Liquid pressure recovery factor	dimensionless	dimensionless
F_{LP}	Product of the liquid pressure recovery factor of a valve with attached fittings and the piping geometry factor	dimensionless	dimensionless
f_p	Frequency, peak, generated inside pipe	Hz	Hz
F_P	Piping geometry factor	dimensionless	dimensionless
f_o	Frequency, coincidence	Hz	Hz
g_c	Gravitational constant	32.17 lbm-ft/lbf-s^2	[3]
k	Ratio of specific heats	dimensionless	dimensionless
L_g	Correction for pipe Mach number	dB	dB
L_{pi}	Sound pressure level, internal	dB	dB
L_a	"A"-weighted sound level	dB (A)	dB (A)
M_j	Mach number, freely expanded, in the jet	dimensionless	dimensionless
M_n	Mach number	dimensionless	dimensionless
M_W	Molecular weight	lbm/lbm-mole	kg/kg-mole
N_O	Number of apparent, independent, flow passages in the valve trim	dimensionless	dimensionless
N	Numerical constants	[4]	[4]
P_a	Pressure, outside pipe, absolute	lbf/ft^2	Pa
P_1	Pressure, upstream, absolute	lbf/ft^2	Pa
P_2	Pressure, downstream, absolute	lbf/ft^2	Pa
P_{2B}	Pressure, outlet at break point, absolute	lbf/ft^2	Pa
P_{2C}	Pressure, outlet at critical flow conditions, absolute	lbf/ft^2	Pa
P_{2CE}	Pressure, outlet where region of constant acoustic efficiency begins, absolute	lbf/ft^2	Pa
P_{VC}	Pressure, vena contracta, at subsonic flow conditions, absolute	lbf/ft^2	Pa

Symbol	Description	Customary US Units	SI Units
P_{vcc}	Pressure, vena contracta, at critical flow conditions, absolute	lbf/ft^2	Pa
P_o	Pressure, standard, reference	2116 lbf/ft^2 [5]	101325 Pa
r	Radial distance centerline of pipe to observer [6]	ft	m
R	Universal Gas Constant	1545 ft-lbf / lbm-mol-°R	8314 J/ kgmole-K
T_1	Temperature, upstream, absolute	°R	K
T_2	Temperature, downstream, absolute	°R	K
T_{vc}	Temperature, vena contracta, at subsonic flow conditions, absolute	°R	K
T_{vcc}	Temperature, vena contracta, at critical flow conditions, absolute	°R	K
t_p	Pipe wall thickness	ft	m
T_L	Transmission loss	dB	dB
T_{Lfo}	Transmission loss at coincidence frequency	dB	dB
ΔT_{Lfp}	Correction for ratio of peak frequency and coincidence frequency	dB	dB
U_{vc}	Velocity, vena contracta, at subsonic flow conditions	ft/s	m/s
U_{vcc}	Velocity, vena contracta, at critical flow conditions	ft/s	m/s
w	Mass flow rate	lbm/s	kg/s
W_m	Stream power of mass flow	ft-lbf/s	W
W_{ms}	Stream power of mass flow at sonic velocity	ft-lbf/s	W
w_s	Mass flow rate at sonic velocity	lbm/s	kg/s
W_a	Sound power	ft-lbf/s	W
α	Recovery correction factor	dimensionless	dimensionless
η	Acoustical efficiency factor	dimensionless	dimensionless
ρ_1	Mass density, upstream	lbm/ft^3	kg/m^3
ρ_2	Mass density, downstream	lbm/ft^3	kg/m^3

NOTES:

1) Units for valve flow coefficient K_V are m^3/h. Substitute 1.157 K_V for C_V. The SI unit is $A_V = 2.40 \times 10^{-5} C_V$. K_V is not SI; its use is discouraged.
2) Usually, nominal diameter can be used with little loss in accuracy.
3) g_c is not required in the SI system; use a value = 1.00 in the equations.
4) Values of numerical constants are given in Table 1.
5) 2116 lbf/ft^2 = 14.696 lbf/in^2
6) The distance r is typically taken as 1 m (3 ft) plus the outer pipe radius.

Table 1 — Numerical constants, N

Constant		Units Used in Equations				
	N	D_i, D_j r, t_p	W_a	ρ_2	c_2	P_1,P_2 P_a, P_o
N_J	1.5×10^{-2} 4.6×10^{-3}	ft m				
N_L	5.7×10^{10} 8.0×10^{8}	ft m	ft-lbf/s W	lbm/ft^3 kg/m^3	ft/s m/s	
N_T	1.1×10^{-7} 1.1×10^{-7}	ft m				lbf/ft^2 Pa
N_F	1.6×10^{4} 5.0×10^{3}	ft m				
N_P	1.5×10^{-4} 1.3×10^{-5}	ft m				lbf/ft^2 Pa
N_S	7.0×10^{-3} 6.5×10^{-4}	ft m				

4 Pressures and pressure ratios

The pressure in the vena contracta is developed from the definition of F_L (see ANSI/ISA-S75.01):

$$P_{vc} = P_1 - \frac{(P_1 - P_2)}{F_L^2} \quad (4.1)$$

NOTE: When the valve has attached fittings, replace F_L with F_{LP}/F_P.

The pressure in the vena contracta at critical flow conditions is:

$$P_{vcc} = P_1\left(\frac{2}{k+1}\right)^{\left(\frac{k}{k-1}\right)} \quad (4.2)$$

The downstream pressure where sonic flow begins is:

$$P_{2C} = P_1 - F_L^2(P_1 - P_{vcc}) \quad (4.3)$$

NOTE: When the valve has attached fittings, replace F_L with F_{LP}/F_P.

The factor α, the ratio between the external pressure ratio and the internal pressure ratio at critical pressure drop, is defined:

$$\alpha = \frac{\left(\frac{P_1}{P_{2C}}\right)}{\left(\frac{P_1}{P_{vcc}}\right)} = \frac{P_{vcc}}{P_{2C}} \tag{4.4}$$

The downstream pressure at the break point between Regimes III and IV (see Section 5 for definitions of regimes) is:

$$P_{2B} = \frac{P_1}{\alpha}\left(\frac{1}{k}\right)^{\left(\frac{k}{k-1}\right)} \tag{4.5}$$

The downstream pressure at the start of the region of "constant acoustic efficiency," where any further decrease in P_2 will result in no increase in noise, is:

$$P_{2CE} = \frac{P_1}{22\alpha} \tag{4.6}$$

5 Regime definition

A control valve controls flow by converting pressure energy into kinetic energy; some of this energy is transferred to the pipe wall as vibration, and a portion of this is radiated as noise. Most of the energy is converted to heat through viscous friction.

At the vena contracta there is a pressure that may be even lower than the downstream pressure.

The different regimes of noise generation are the result of differing sonic phenomena or reactions between the molecules in the gas and the sonic shock cells.

In Regime I, flow is subsonic and the gas pressure is partially recovered or recompressed, thus the use of the factor F_L.

In Regime II, sonic flow exists, with interaction between shock cells and with turbulent choked flow mixing. Pressure recovery is less as the limit of Regime II is approached.

In Regime III no isentropic pressure recovery takes place.

In Regime IV the shock cell structure diminishes as a "Mach disk" is formed.

In Regime V there is a constant acoustic efficiency.

IF:	$P_1 > P_2 \geq P_{2C}$	THEN REGIME = I	(5.1)
IF:	$P_{2C} > P_2 \geq P_{vcc}$	THEN REGIME = II	(5.2)
IF:	$P_{vcc} > P_2 \geq P_{2B}$	THEN REGIME = III	(5.3)
IF:	$P_{2B} > P_2 \geq P_{2CE}$	THEN REGIME = IV	(5.4)
IF:	$P_{2CE} > P_2 \geq 0$	THEN REGIME = V	(5.5)

6 Preliminary calculations

N_o is the number of apparent independent flow passages. Note that for cage-type trims this is usually the number of openings in the cage. Where a number of flow passages are in close proximity, as in some cage trims, the values require tests. The valve style modifier F_d (see Table 2) is:

$$F_d = N_o^{(-1/2)} \qquad (6.1)$$

For flow-to-open valves with contoured plugs at small openings, a special case occurs:

$$F_d = 0.7\left(\frac{N_S C_v F_L}{4\,D_i^2}\right)^{(1/2)} \qquad (6.2)$$

F_d (maximum) = 0.7 for this equation.

NOTE: Use the required value of C_v, not the rated value of C_v.

The jet diameter is:

$$D_j = N_J F_d (C_v F_L)^{(1/2)} \qquad (6.3)$$

NOTE: Use the required value of C_v, not the rated value of C_v.

The Mach number in a freely expanded jet is:

$$M_j = \left\{\left(\frac{2}{k-1}\right)\left[\left(\frac{P_1}{\alpha\, P_2}\right)^{\left(\frac{k}{k-1}\right)} - 1\right]\right\}^{(1/2)} \qquad (6.4)$$

7 Regime I (subsonic flow)

The temperature in the vena contracta is:

$$T_{vc} = T_1\left(\frac{P_{vc}}{P_1}\right)^{\left(\frac{k-1}{k}\right)} \quad (7.1)$$

The speed of sound ($M_n = 1$) is:

$$c_{vc} = \left(\frac{kRg_cT_{vc}}{M_w}\right)^{(1/2)} \quad (7.2)$$

Table 2 — Typical N_o and F_d factors

	N_o		F_d	
	Flow to:		Flow to:	
Valve Type	Open	Close	Open	Close
Single-Seat Globe	2.0	1.0	0.7[2]	1.0
Butterfly, Standard	2.0	2.0	0.7	0.7
Angle	2.0	1.0	0.7	1.0
Eccentric, Rotary Plug	2.0	1.0	0.7	1.0
Ball	1.0	1.0	1.0	1.0
Cage	[1]	[1]		
Double Seat, Parabolic	4.0	4.0	0.5	0.5

NOTES:

1) Use the number of apparent independent openings in the cage at the actual valve stem position (refer to the manufacturer's catalog for the valve under consideration).

2) See Equation 6.2.

The gas velocity in the vena contracta is:

$$U_{vc} = \left\{2g_c\left(\frac{k}{k-1}\right)\left[1-\left(\frac{P_{vc}}{P_1}\right)^{\left(\frac{k-1}{k}\right)}\right]\frac{P_1}{\rho_1}\right\}^{(1/2)} \quad (7.3)$$

The stream power of the fluid in the vena contracta is:

$$W_m = \frac{w(U_{vc})^2}{2g_c} \qquad (7.4)$$

By definition, the Mach number is:

$$M_n = \frac{U_{vc}}{c_{vc}} \qquad (7.5)$$

The acoustic efficiency for Regime I is:

$$\eta_{\mathrm{I}} = (1 \times 10^{-4})(M_n^{3.6}) \qquad (7.6)$$

The sound power generated is:

$$W_a = \eta_{\mathrm{I}} W_m F_L^2 \qquad (7.7)$$

NOTE: When the valve has attached fittings, replace F_L with F_{LP}/F_P.

The peak frequency of the generated noise from the geometry is:

$$f_p = \frac{0.2U_{vc}}{D_j} \qquad (7.8)$$

8 Common equations for sonic and above

The temperature in the vena contracta at sonic conditions is:

$$T_{vcc} = \frac{2T_1}{k+1} \qquad (8.1)$$

The orificial velocity of sound is:

$$c_{vcc} = \left(\frac{k\,R\,g_c T_{vcc}}{M_w}\right)^{(1/2)} \qquad (8.2)$$

The gas velocity in the vena contracta, at critical conditions, is:

$$U_{vcc} = \left\{2g_c\left(\frac{k}{k-1}\right)\left[1-\left(\frac{P_{vcc}}{P_1}\right)^{\left(\frac{k-1}{k}\right)}\right]\frac{P_1}{\rho_1}\right\}^{(1/2)} \tag{8.3}$$

Stream power, at sonic (choked) velocity is:

$$W_{ms} = \frac{wU_{vcc}^2}{2g_c} \tag{8.4}$$

9 Regime II

The acoustic efficiency for Regime II is:

$$\eta_{\mathrm{II}} = (1\times 10^{-4})(\mathrm{M}_j)^{(6.6F_L^2)} \tag{9.1}$$

NOTE: When the valve has attached fittings, replace F_L with F_{LP}/F_P.

The sound power generated is:

$$W_a = \eta_{\mathrm{II}} W_{ms}\left(\frac{P_1-P_2}{P_1-P_{vcc}}\right) \tag{9.2}$$

The peak frequency of the generated noise from the geometry is:

$$f_p = \frac{0.2\mathrm{M}_j c_{vcc}}{D_j} \tag{9.3}$$

10 Regime III

The acoustic efficiency for Regime III is:

$$\eta_{\mathrm{III}} = (1\times 10^{-4})(\mathrm{M}_j)^{(6.6F_L^2)} \tag{10.1}$$

NOTE: When the valve has attached fittings, replace F_L with F_{LP}/F_P.

The sound power generated is:

$$W_a = \mathrm{h}_{III} W_{ms} \tag{10.2}$$

The peak frequency of the generated noise from the geometry is:

$$f_p = \frac{0.2 \mathrm{M}_j c_{vcc}}{D_j} \qquad (10.3)$$

11 Regime IV

The acoustic efficiency for Regime IV is:

$$\eta_{IV} = (1 \times 10^{-4})\left(\frac{\mathrm{M}_j^2}{2}\right)(\sqrt{2})^{(6.6 F_L^2)} \qquad (11.1)$$

NOTE: When the valve has attached fittings, replace F_L with F_{LP}/F_P.

The sound power generated is:

$$W_a = \eta_{\mathrm{IV}} W_{ms} \qquad (11.2)$$

The peak frequency of the generated noise from the geometry is:

$$f_p = \frac{0.35 c_{vcc}}{1.25 D_j (\mathrm{M}_j^2 - 1)^{(1 \S 2)}} \qquad (11.3)$$

12 Regime V

$$\mathrm{M}_j = \left\{\left(\frac{2}{k-1}\right)\left[(22)^{\left(\frac{k-1}{k}\right)} - 1\right]\right\}^{(1/2)} \qquad (12.1)$$

The acoustic efficiency for Regime V is:

$$\eta_{V} = (1 \times 10^{-4})\left(\frac{M_j^2}{2}\right)(\sqrt{2})^{(6.6F_L^2)} \tag{12.2}$$

NOTE: When the valve has attached fittings, replace F_L with F_{LP}/F_P .

The sound power generated is:

$$W_a = \eta_V W_{ms} \tag{12.3}$$

The peak frequency of the generated noise from the geometry is:

$$f_p = \frac{0.35 c_{vcc}}{1.25 D_j (M_j^2 - 1)^{(1/2)}} \tag{12.4}$$

13 Noise calculations

The downstream temperature T_2 may be determined using thermodynamic isenthalpic relationships, provided that the necessary fluid properties are known. However, if the fluid properties are not known, T_2 may be taken as approximately equal to T_1.

Downstream density is:

$$\rho_2 = \rho_1\left(\frac{P_2}{P_1}\right) \tag{13.1}$$

The speed of sound under downstream conditions is:

$$c_2 = \left(\frac{kRg_c T_2}{M_w}\right)^{(1/2)} \tag{13.2}$$

This is calculated in order to calculate the Mach number. Internal sound pressure level is:

$$L_{pi} = 10 \log_{10}\left(\frac{N_L W_a \rho_2 c_2}{D_i^2}\right) \tag{13.3}$$

NOTE: The reference pressure used in (13.3) is 2 x 10^{-4} μbar equivalent to (2 x 10^{-5} Pa).

The transmission loss at the coincidence frequency at the distance r is:

$$T_{Lfo} = 10 \log_{10}\left[N_T\left(\frac{D_i^3}{rt_p^2}\right)\frac{1}{\left(\frac{P_2}{P_o} + 1\right)}\left(\frac{P_a}{P_o}\right)\right] \tag{13.4}$$

NOTE: The fraction P_a/P_o is a correction for local barometric pressure.

The pipe coincidence frequency is:

$$f_o = \frac{N_F}{4\pi D_i} \tag{13.5}$$

Sound travels through the pipe wall depending on the relationship between the peak generated frequency and the pipe coincidence frequency:

If $f_p \le f_o$: then $\Delta T_{Lfp} = 20 \log_{10}\left(\frac{f_o}{f_p}\right)$ (13.6)

If $f_p > f_o$ and $f_p \le 4f_o$: then $\Delta T_{Lfp} = 13 \log_{10}\left(\frac{f_p}{f_o}\right)$ (13.7)

If $f_p > 4f_o$: then $\Delta T_{Lfp} = 20 \log_{10}\left(\frac{f_p}{4f_o}\right) + 7.8$

(13.8)

Transmission loss is:

$$T_L = T_{Lfo} - \Delta T_{Lfp} \tag{13.9}$$

The transmission loss correction for downstream fluid velocity is approximately (limited to 0.3 Mach, maximum):

$$L_g = 16 \log_{10}\left[\frac{1}{1 - \left(\frac{N_p P_1 C_v F_L}{D_i^2 P_2}\right)}\right] \tag{13.10}$$

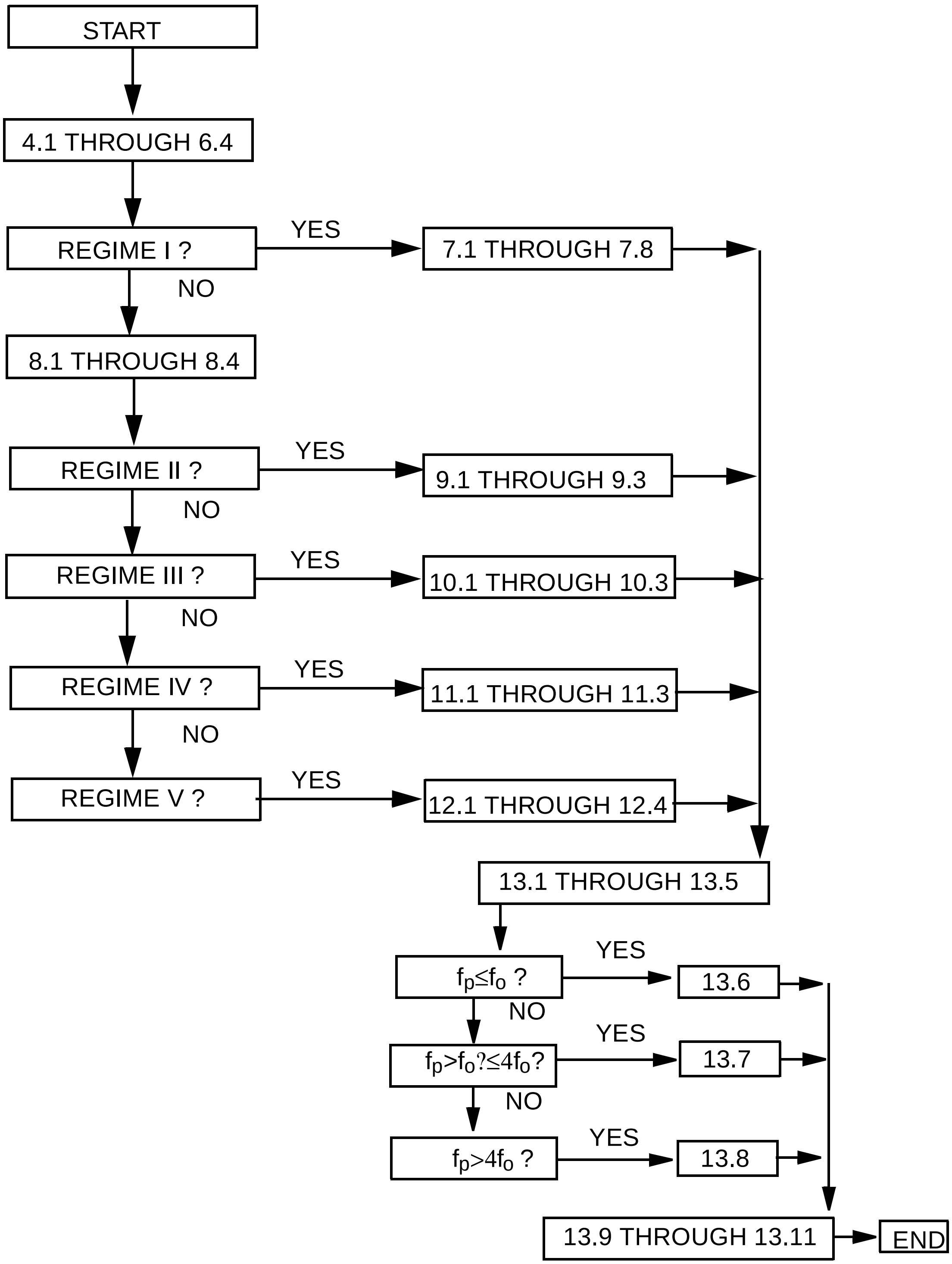
NOTE: Use the required C_V, not the rated value of C_V.

NOTE: When the valve has attached fittings, replace F_L with F_{LP}/F_P.

The sound level is:

$$L_a = 5 + L_{pi} + T_L + L_g \tag{13.11}$$

14 Calculation flow chart*



*Numbers are equation numbers.

Appendix A — References

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Appendix B — Example

This is not a part of the standard, but is included to show how it is used. Values are given to more places than justified to make checking easier.

Given Data

4-inch valve; maximum C_V = 210; C_V used = 210; F_L = 0.8. Inlet pipe nominal 8 inch; outlet pipe same; wall is 0.322 inch.

Fluid is vapor: 165 psia; density, 0.341817 lbm/ft^3; T = 350°F

k = 1.33

Molecular weight, 18.

Downstream pressure, 70 psia; equivalent sound orifices = 1. Installed flow-to-close.

Actual atmospheric pressure, 14.696 psia.

The numbers on the right-hand side, for example, (4.1), are the equation numbers as used in this standard.

From calculations based on ANSI/ISA-S75.01, Flow Equations for Sizing Control Valves, the following five values are calculated:

K_i = 1.2187500

F_P = 0.92715341

F_{LP} = 0.74568802

F_{LP}/F_P = 0.80427682

w = 50247.711 lbm/hr

$$P_{vc} = P_1 - \frac{(P_1 - P_2)}{F_L^2} \qquad (4.1)$$

P_1 = 23760 lbf/ft^2

P_2 = 10080 lbf/ft^2

F_{LP}/F_P = 0.80427682 (F_{LP}/F_P used because fittings are attached)

Result

P_{vc} = 2611.7227 lbf/ft^2

$$P_{vcc} = P_1\left(\frac{2}{k+1}\right)^{\left(\frac{k}{k-1}\right)} \qquad (4.2)$$

P_1 = 23760 lbf/ft^2

k = 1.33

Result

P_{vcc} = 12839.048 lbf/ft^2

$$P_{2C} = P_1 - F_L^2(P_1 - P_{vcc}) \tag{4.3}$$

P_1 = 23760 lbf/ft^2

F_{LP}/F_P = .080427682 (F_{LP}/F_P used because fittings are attached)

P_{vcc} = 12839.048 lbf/ft^2

Result

P_{2C} = 16695.660 lbf/ft^2

$$\alpha = \frac{\left(\frac{P_1}{P_{2C}}\right)}{\left(\frac{P_1}{P_{vcc}}\right)} = \frac{P_{vcc}}{P_{2C}} \tag{4.4}$$

P_{vcc} = 12839.048 lbf/ft^2

P_{2C} = 16695.660 lbf/ft^2

Result

α = 0.76900512

$$P_{2B} = \frac{P_1}{\alpha}\left(\frac{1}{k}\right)^{\left(\frac{k}{k-1}\right)} \tag{4.5}$$

P_1 = 23760 lbf/ft^2

α = 0.76900512

k = 1.33

Result

P_{2B} = 9789.4346 lbf/ft^2

$$P_{2CE} = \frac{P_1}{22\alpha} \tag{4.6}$$

P_1 = 23760 lbf/ft^2

α = 0.76900512

Result

P_{2CE} = 1404.4120 lbf/ft^2

IF: $P_{vcc} > P_2 \geq P_{2B}$; then Regime = III (5.3)

12839.048 > 10080 > 9789.4346 Thus, regime is III.

$$F_d = N_o^{(-1/2)} \tag{6.1}$$

N_o = 1.0000

Result

F_d = 1.00000

$$D_j = N_J F_d (C_v F_L)^{(1/2)} \tag{6.3}$$

N_J = 1.5 X 10^{-2}

F_d = 1.00

C_v = 210.0

F_{LP}/F_P = 0.80427682 (fittings attached)

Result

D_j = 0.19494122 ft

$$\mathrm{M}_j = \left\{\left(\frac{2}{k-1}\right)\left[\left(\frac{P_1}{\alpha P_2}\right)^{\left(\frac{k-1}{k}\right)} - 1\right]\right\}^{(1/2)} \tag{6.4}$$

k = 1.33

P_1 = 23760 lbf/ft^2

P_2 = 10080 lbf/ft^2

α = 0.76900512

Result

M_j = 1.3934534

$$T_{vcc} = \frac{2T_1}{k+1} \tag{8.1}$$

k = 1.33

T_1 = 809.68988°R

Result

T_{vcc} = 695.01270 R

$$c_{vcc} = \left(\frac{kRg_cT_{vcc}}{M_w}\right)^{(1/2)} \tag{8.2}$$

k = 1.33

R = 1545 ft-lbf/lbm-mole-°R

T_{vcc} = 695.01270°R

g_c = 32.17 lbm-ft/lbf-s^2

M_W = 18.0

Result

c_{vcc} = 1597.6282 ft/s

$$U_{vcc} = \left\{2g_c\left(\frac{k}{k-1}\right)\left[1-\left(\frac{P_{vcc}}{P_1}\right)^{\left(\frac{k-1}{k}\right)}\right]\frac{P_1}{\rho_1}\right\}^{(1/2)} \tag{8.3}$$

k = 1.33

P_{vcc} = 12839.048 lbf/ft^2

P_1 = 23760 lbf/ft^2

ρ_1 = 0.34181735 lbm/ft^3

Result

U_{vcc} = 1597.7712 ft/s

$$W_{ms} = \frac{wU_{vcc}^{2}}{2g_c} \tag{8.4}$$

w = 50247.711 lbm/hr or 50000/3600 lbm/s

U_{vcc} = 1597.7712 ft/s

g_c = 32.17 lbm-ft/lbf-s^2

Result

W_{ms} = 553811.56 ft-lbf/s

$$\eta_{\text{III}} = (1 \times 10^{-4})(\mathrm{M}_j)^{(6.6F_L^2)} \tag{10.1}$$

M_j = 1.3934534

F_{LP}/F_P = 0.80427682

Result

η_{III} = 0.00041226027

$$W_a = \eta_{III} W_{ms} \tag{10.2}$$

W_{ms} = 553811.56 ft-lbf/s

η_{III} = 0.00041226027

Result

W_a = 228.31450 ft-lbf/s

$$f_p = \frac{0.2 \mathrm{M}_j c_{vcc}}{D_j} \tag{10.3}$$

c_{vcc} = 1597.6282 ft/s

M_j = 1.3934534

D_j = 0.19494122 ft

Result

f_p = 2283.9912 Hz

$$\rho_2 = \rho_1 \left(\frac{P_2}{P_1}\right) \tag{13.1}$$

ρ_1 = 0.34181735 lbm/ft^3

P_1 = 23760 lbf/ft^2

P_2 = 10080 lbf/ft^2

Result

ρ_2 = 0.14501342 lbm/ft^2

$$c_2 = \left(\frac{kRg_cT_2}{M_w}\right)^{(1/2)} \tag{13.2}$$

k = 1.33

R = 1545 ft-lbf/lbm-mole-°R

T_2 = 809.68988°R

g_c = 32.17 lbm-ft/lbf-s^2

M_w = 18.0

Result

c_2 = 1724.4027 ft/s

$$L_{pi} = 10 \log_{10}\left(\frac{N_L W_a \rho_2 c_2}{D_i^2}\right) \qquad (13.3)$$

N_L = 5.7 x 10^{10}

W_a = 228.31450 ft-lbf/s

ρ_2 = 0.14501342 lbm/ft^3

c_{vcc} = 1597.6282 ft/s

D_i = 0.6666667 ft

Result

L_{pi} = 158.64638 dB

$$T_{Lfo} = 10 \log_{10}\left[N_T\left(\frac{D_i^3}{rt_p^2}\right)\frac{1}{\left(\frac{P_2}{P_o}+1\right)}\frac{P_a}{P_o}\right] \qquad (13.4)$$

N_T = 1.1 X 10^{-7}

D_i = 0.6666667 ft

r = 3.5 ft

t_p = 0.322/12 ft

P_2 = 10080 lbf/ft^2

P_o = 2166.2241 lbf/ft^2

P_a = 2166.2241 lbf/ft^2

Result

T_{Lfo} = –56.489620 dB

$$f_o = \frac{N_F}{4\pi D_i} \qquad (13.5)$$

N_F = 1.6 X 10^4

π = 3.14159265359

D_i = 0.6666667 ft

Result

f_o = 1909.8608 Hz

If $f_p > f_o$ and $f_p \leq 4f_o$; then $\Delta T_{Lfp} = 13 \log_{10}\left(\frac{f_p}{f_o}\right)$ (13.6)

2283.9912 > 1909.8608 and 2283.9912 ≤ 7639.4432

f_p = 2283.9912 Hz

f_o = 1909.8608 Hz

Result

ΔT_{Lfp} = 1.0100050 dB

Transmission loss is: $T_L = T_{Lfo} - \Delta T_{Lfp}$ (13.8)

T_{Lfo} = –56.489620 dB

ΔT_{Lfp} = 1.0100050 dB

Result

T_L = –57.499626 dB

$$L_g = 16 \log_{10}\left[\frac{1}{1 - \left(\frac{N_p P_1 C_v F_L}{D_1^2 P_2}\right)}\right] \quad (13.9)$$

N_P = 1.5 X 10^{-4}

P_1 = 23760 lbf/ft^2

C_v = 210.0

F_{LP}/F_P = 0.80427682 (used because of fittings)

D_i = 0.6666667 ft

P_2 = 10080 lbf/ft^2

Result

L_g = 1.0026389 dB

$$L_a = 5 + L_{pi} + T_L + L_g \quad (13.10)$$

T_L = –57.499626 dB

L_g = 1.0026389 dB

L_{pi} = 158.31476 dB

Result

L_a = 107.14939 dB (A)

Use: 107 dB (A)

Check downstream Mach:

w = 50247.711 lb/hr

ρ_2 = 0.14501342 lb/ft^3

D_i = 0.6666667 ft

$$U_2 = \frac{\text{Volume flow}}{\text{Flow area}}$$

$$\text{Volume flow} = \left(\frac{50247.711}{3600}\right)\left(\frac{1}{0.14501342}\right)$$

= 96.2511 ft^3/sec

$$\text{Flow area} = \left(\frac{0.6666667}{2}\right)^2 \pi = 0.3490659 \text{ ft}^2$$

U_2 = 275.73923 ft/sec

$$M_{n2} = \frac{\text{vel}}{c} = \frac{275.73923}{1724.4027} = 0.1599$$

Thus, calculation is appropriate.

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