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**Industrial-process control valves—
Part 8-3: Noise considerations—
Control valve aerodynamic noise
prediction method**

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Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal of establishing a Japanese Industrial Standard from Japan Valve Manufacturers' Association (JVMA), with a draft being attached, based on the provision of Article 12 Clause 1 of the Industrial Standardization Law.

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JIS B 2005 consists of the following parts under the general title "*Industrial-process control valves*":

JIS B 2005-1 *Part 1: Control valve terminology and general considerations*

JIS B 2005-2-1 *Part 2-1: Flow capacity—Sizing equations for fluid flow under installed conditions*

JIS B 2005-2-3 *Part 2-3: Flow capacity—Test procedures*

JIS B 2005-2-4 *Part 2: Flow capacity—Section Four: Inherent flow characteristics and rangeability*

JIS B 2005-3-1 *Part 3-1: Dimensions—Face-to-face dimensions for flanged, two-way, globe-type, straight pattern and centre-to-face dimensions for flanged, two-way, globe-type, angle pattern control valves*

JIS B 2005-3-2 *Part 3-2: Dimensions—Face-to-face dimensions for rotary control valves except butterfly valves*

JIS B 2005-3-3 *Part 3-3: Dimensions—End-to-end dimensions for butt weld, two-way, globe-type, straight pattern control valves*

JIS B 2005-4 *Part 4: Inspection and routine testing*

JIS B 2005-5 *Part 5: Marking*

JIS B 2005-6-1 *Part 6: Mounting details for attachment of positioners to control valves—Section 1: Positioner mounting on linear actuators*

JIS B 2005-6-2 *Part 6-2: Mounting details for attachment of positioners to control valves—Positioner mounting on rotary actuators*

JIS B 2005-7 *Part 7: Control valve data sheet*

JIS B 2005-8-1 *Part 8: Noise considerations—Section One: Laboratory measurement of noise generated by aerodynamic flow through control valves*

JIS B 2005-8-2 *Part 8: Noise considerations—Section 2: Laboratory measurement of noise generated by hydrodynamic flow through control valves*

JIS B 2005-8-3 *Part 8-3: Noise considerations—Control valve aerodynamic noise prediction method*

JIS B 2005-8-4 *Part 8-4: Noise considerations—Prediction of noise generated by hydrodynamic flow*

Industrial-process control valves— Part 8-3: Noise considerations— Control valve aerodynamic noise prediction method

Introduction

This Japanese Industrial Standard has been prepared based on the second edition of **IEC 60534-8-3** published in 2000 without modifying the technical contents.

The mechanical stream power, as well as acoustical efficiency factors, are calculated for various flow regimes. These acoustical efficiency factors give the proportion of the mechanical stream power which is converted into internal sound power.

This method also provides for the calculation of the internal sound pressure and the peak frequency for this sound pressure, which is of special importance in the calculation of the pipe transmission loss.

At present, a common requirement by valve users is the knowledge of the sound pressure level outside the pipe, typically 1 m downstream of the valve or expander and 1 m from the pipe wall. This Standard offers a method to establish this value.

The equations in this Standard make use of the valve sizing factors as used in **JIS B 2005-1** and **JIS B 2005-2-1**.

In the usual control valve, little noise travels through the wall of the valve. The noise of interest is only that which travels downstream of the valve and inside of the pipe and then escapes through the wall of the pipe to be measured typically at 1 m downstream of the valve body and 1 m away from the outer pipe wall.

Secondary noise sources may be created where the gas exits the valve outlet at higher Mach numbers. This method allows for the estimation of these additional sound levels which can then be added logarithmically to the sound levels created within the valve. See clauses **5** and **6** for Mach numbers up to 0.3 and clause **7** for Mach numbers greater than 0.3.

Although this prediction method cannot guarantee actual results in the field, it yields calculated predictions within 5 dB(A) for the majority of noise data from tests under laboratory conditions (see **JIS B 2005-8-1**).

The bulk of the test data used to validate the method was generated using air at moderate pressures and temperatures; however, it is believed that the method is generally applicable to other gases and vapours and at higher pressures. Uncertainties become greater as the fluid behaves less perfectly for extreme temperatures and for downstream pressures far different from atmospheric, or near the critical point. The equations include terms which account for fluid density and the ratio of specific heat.

NOTE : Laboratory air tests conducted with up to 1 830 kPa (18.3 bar) upstream pressure and up to 1 600 kPa (16.0 bar) downstream pressure and steam tests up to 225 °C showed good agreement with the calculated values.

The transmission loss equations are based on a rigorous analysis of the interaction between the sound waves existing in the pipe and the many coincidence frequencies in the pipe wall. The wide tolerances in pipe wall thickness allowed in commercial

pipe severely limit the value of the very complicated mathematical approach required for a rigorous analysis; therefore, a simplified method is used.

Example calculations are given in Annex A.

This method is based on the **JIS B 2005** (series) listed in clause 2 and the references given in Annex B.

1 Scope and limitations

This Standard establishes a theoretical method to predict the external sound-pressure level generated in a control valve and within adjacent pipe expanders by the flow of compressible fluids.

This method considers only single-phase dry gases and vapours and is based on the perfect gas laws.

This Standard addresses only the noise generated by aerodynamic processes in valves and in the connected piping. It does not consider any noise generated by reflections, mechanical vibrations, unstable flow patterns and other unpredictable behaviour.

It is assumed that the downstream piping is straight for a length of at least 2 m from the point where the noise measurement is made.

This method is valid only for steel and steel alloy pipes [see equations (38) and (40) in 5.6].

The method is applicable to the following single-stage valves: globe (straight pattern and angle pattern), butterfly, rotary plug (eccentric, spherical), ball, and valves with cage trims. Specifically excluded are the full bore ball valves where the product $F_p C$ exceeds 50 % of the rated flow coefficient.

For limitations on special low noise trims not covered by this Standard, see 6.5. When the Mach number in the valve outlet exceeds 0.3 for standard trim or 0.2 for low noise trim, the procedure in clause 7 is used.

The Mach number limits in this Standard are as follows:

Mach number location	Mach number limit		
	Clause 5 Standard trim	Clause 6 Noise-reducing trim	Clause 7 High Mach number applications
Freely expanded jet M_j	No limit	No limit	No limit
Valve outlet M_o	0.3	0.2	1.0
Downstream reducer inlet M_r	Not applicable	Not applicable	1.0
Downstream pipe M_2	0.3	0.2	0.8

NOTE : The International Standard corresponding to this Standard is as follows.

IEC 60534-8-3:2000 *Industrial-process control valves—Part 8-3: Noise considerations—Control valve aerodynamic noise prediction method* (IDT)

In addition, symbols which denote the degree of correspondence in the contents between the relevant International Standard and **JIS** are IDT (identical), MOD (modified), and NEQ (not equivalent) according to **ISO/IEC Guide 21**.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS B 2005 (series) *Industrial-process control valves*

NOTE : Corresponding International Standards: IEC 60534 (all parts) *Industrial-process control valves* (IDT)

3 Terms and definitions

For the purpose of this Standard, all of the terms and definitions given in the **JIS B 2005** series apply, as well as the following:

3.1 acoustical efficiency

ratio of the stream power converted into sound power to the stream power of the mass flow

3.2 external coincidence frequency

frequency at which the external acoustic wavespeed is equal to the bending wavespeed in a plate of equal thickness to the pipe wall

3.3 internal coincidence frequency

lowest frequency at which the acoustic and structural axial wave numbers are equal for a given circumferential mode, thus resulting in the minimum transmission loss

3.4 fluted vane butterfly valve

butterfly valve which has flutes (grooves) on the face(s) of the disk

These flutes are intended to shape the flow stream without altering the seating line or seating surface.

3.5 independent flow passage

flow passage where the exiting flow is not affected by the exiting flow from adjacent flow passages

3.6 peak frequency

frequency at which the internal sound pressure is maximum

3.7 valve style modifier F_d

ratio of the hydraulic diameter of a single flow passage to the diameter of a circular orifice, the area of which is equivalent to the sum of areas of all identical flow passages at a given travel

4 Symbols and units

The symbols and units used in this Standard shall be as given in table 1.

Table 1 Symbols and units

Symbol	Description	Unit
A	Area of a single flow passage	m^2
A_n	Total flow area of last stage of multistage trim with n stages at given travel	m^2
C	Flow coefficient (K_v and C_v)	various (see JIS B 2005-1)
C_n	Flow coefficient for last stage of multistage trim with n stages	various (see JIS B 2005-1)
c_{vc}	Speed of sound in the <i>vena contracta</i> at subsonic flow conditions	m/s
c_{vcc}	Speed of sound in the <i>vena contracta</i> at critical flow conditions	m/s
c_2	Speed of sound at downstream conditions	m/s
D	Valve outlet diameter	m
d	Diameter of a flow passage (for other than circular, use d_H)	m
d_H	Hydraulic diameter of a single flow passage	m
d_i	Smaller of valve outlet or expander inlet internal diameters	m
D_i	Internal downstream pipe diameter	m
D_j	Jet diameter at the <i>vena contracta</i>	m
d_o	Diameter of a circular orifice, the area of which equals the sum of areas of all flow passages at a given travel	m
F_d	Valve style modifier	Dimensionless
F_L	Liquid pressure recovery factor of a valve without attached fittings	Dimensionless ^{d)}
F_{Ln}	Liquid pressure recovery factor of last stage of low noise trim	Dimensionless
F_{LP}	Combined liquid pressure recovery factor and piping geometry factor of a control valve with attached fittings	Dimensionless ^{d)}
F_p	Piping geometry factor	Dimensionless
f_g	External coincidence frequency	Hz
f_o	Internal coincidence pipe frequency	Hz
f_p	Generated peak frequency	Hz
f_{pR}	Generated peak frequency in valve outlet or reduced diameter of expander	Hz
f_r	Ring frequency	Hz
G_x, G_y	Frequency factors (see table 5)	Dimensionless
l	Length of a radial flow passage	m
l_w	Wetted perimeter of a single flow passage	m
L_{peR}	A-weighted sound-pressure level 1 m from pipe wall, caused by pipe expander-induced gas turbulence	dB(A) (ref P_o)
L_g	Correction for Mach number	dB (ref P_o)
L_{pAe}	A-weighted sound-pressure level external of pipe	dB(A) (ref P_o)
$L_{pAe,1m}$	A-weighted sound-pressure level 1 m from pipe wall	dB(A) (ref P_o)

Table 1 (continued)

Symbol	Description	Unit
L_{pi}	Internal sound-pressure level at pipe wall (see 5.6)	dB (ref P_o)
L_{piR}	Internal sound-pressure level in downstream pipe (see 7.2)	dB (ref P_o)
L_{pS}	Combined A-weighted sound-pressure level 1 m from pipe wall, caused by valve trim and expander	dB(A) (ref P_o)
L_{wi}	Total internal sound power level	dB (ref W_o)
M	Molecular mass of flowing fluid	kg/kmol
M_j	Freely expanded jet Mach number in regimes II to IV	Dimensionless
M_{jn}	Freely expanded jet Mach number of last stage in multistage valve with n stages	Dimensionless
M_{j5}	Freely expanded jet Mach number in regime V	Dimensionless
M_o	Mach number at valve outlet	Dimensionless
M_R	Mach number in the entrance to expander	Dimensionless
M_{vc}	Mach number at the <i>vena contracta</i>	Dimensionless
M_2	Mach number in downstream pipe	Dimensionless
$\dot{m}$	Mass flow rate	kg/s
$\dot{m}_s$	Mass flow rate at sonic velocity	kg/s
N	Numerical constants (see table 2)	Various
N_o	Number of independent and identical flow passages in valve trim	Dimensionless
p_a	Actual atmospheric pressure outside pipe	Pa ^{e)}
p_n	Absolute stagnation pressure at last stage of multistage valve with n stages	Pa
P_o	Reference sound pressure = 2×10^{-5} e)	Pa
p_s	Standard atmospheric pressure ^{a)}	Pa
p_{vc}	Absolute <i>vena contracta</i> pressure at subsonic flow conditions	Pa
p_{vec}	Absolute <i>vena contracta</i> pressure at critical flow conditions	Pa
p_1	Valve inlet absolute pressure	Pa
p_2	Valve outlet absolute pressure	Pa
p_{2B}	Valve outlet absolute pressure at break point	Pa
p_{2C}	Valve outlet absolute pressure at critical flow conditions	Pa
p_{2CE}	Valve outlet absolute pressure where region of constant acoustical efficiency begins	Pa
R	Universal gas constant = 8 314	J/kmol $\times$ K
r_w	Acoustic power ratio (see table 4)	Dimensionless
T_n	Inlet absolute temperature at last stage of multistage valve with n stages	K
T_{vc}	<i>Vena contracta</i> absolute temperature at subsonic flow conditions	K
T_{vec}	<i>Vena contracta</i> absolute temperature at critical flow conditions	K

Table 1 (concluded)

Symbol	Description	Unit
T_1	Inlet absolute temperature	K
T_2	Outlet absolute temperature	K
TL	Transmission loss	dB
TL_R	Transmission loss in downstream pipe	dB
t_p	Pipe wall thickness	m
U_p	Gas velocity in downstream pipe	m/s
U_R	Gas velocity in the inlet of expander	m/s
U_{vc}	<i>Vena contracta</i> velocity at subsonic flow conditions	m/s
W_a	Sound power	W
W_{aR}	Sound power in valve outlet or reduced diameter of expander	W
W_m	Stream power of mass flow	W
W_{mR}	Stream power of mass flow in valve outlet or reduced diameter of expander	W
W_{ms}	Stream power of mass flow rate at sonic velocity	W
W_o	Reference sound power = 10^{-12} e)	W
α	Recovery correction factor	Dimensionless
β	Contraction coefficient for valve outlet or expander inlet	Dimensionless
γ	Specific heat ratio	Dimensionless
η	Acoustical efficiency factor ^{b)}	Dimensionless
ρ_1	Density of fluid at p_1 and T_1	kg/m ³
ρ_2	Density of fluid at p_2 and T_2	kg/m ³
ρ_n	Density of fluid at last stage of multistage valve with n stages at p_n and T_n	kg/m ³
Φ	Relative flow coefficient	Dimensionless
Subscripts		
e	Denotes external	
i	Denotes internal	
n	Denotes last stage or trim	
R	Denotes conditions in downstream pipe or pipe expander	
Notes	a) Standard atmospheric pressure is 101.325 kPa or 1.013 25 bar. b) Subscripts 1, 2, 3, 4 and 5 denote regimes I, II, III, IV and V respectively. c) 1 bar = 10^2 kPa = 10^5 Pa. d) For the purpose of calculating the <i>vena contracta</i> pressure, and therefore velocity, in this Standard, pressure recovery for gases is assumed to be identical to that of liquids. e) Sound power and sound pressure are customarily expressed using the logarithmic scale known as the decibel scale. This scale relates the quantity logarithmically to some standard reference. This standard reference is 2×10^{-5} Pa for sound pressure and 10^{-12} W for sound power.	

5 Valve with standard trim

5.1 Pressures and pressure ratios

There are several pressures and pressure ratios needed in the noise prediction procedure. They are given below.

The *vena contracta* is the region of maximum velocity and minimum pressure. This minimum pressure, which cannot be less than zero absolute, is calculated as follows:

$$p_{vc} = p_1 - \frac{p_1 - p_2}{F_L^2} \dots\dots\dots (1)$$

NOTE 1 This equation is the definition of F_L for subsonic conditions.

NOTE 2 When the valve has attached fittings, replace F_L with F_{LP}/F_p .

NOTE 3 The factor F_L is needed in the calculation of the *vena contracta* pressure. The *vena contracta* pressure is then used to calculate the velocity, which is needed to determine the acoustical efficiency factor.

At critical flow conditions, the pressure in the *vena contracta* is calculated as follows:

$$p_{vcc} = p_1 \left(\frac{2}{\gamma + 1} \right)^{\gamma/(\gamma-1)} \dots\dots\dots (2)$$

The critical downstream pressure where sonic flow in the *vena contracta* begins is calculated from the following equation:

$$p_{2C} = p_1 - F_L^2 (p_1 - p_{vcc}) \dots\dots\dots (3)$$

NOTE 4 When the valve has attached fittings, replace F_L with F_{LP}/F_p .

The correction factor α is the ratio of two pressure ratios:

- a) the ratio of inlet pressure to outlet pressure at critical flow conditions;
- b) the ratio of inlet pressure to *vena contracta* pressure at critical flow conditions.

It is defined as follows:

$$\alpha \equiv \frac{\left(\frac{p_1}{p_{2C}} \right)}{\left(\frac{p_1}{p_{vcc}} \right)} = \frac{p_{vcc}}{p_{2C}} \dots\dots\dots (4)$$

The point at which the shock cell-turbulent interaction mechanism (regime IV) begins to dominate the noise spectrum over the turbulent-shear mechanism (regime III) is known as the break point. See 5.2 for a description of these regimes. The downstream pressure at the break point is calculated as follows:

$$p_{2B} = \frac{p_1}{\alpha} \left(\frac{1}{\gamma} \right)^{\gamma/(\gamma-1)} \dots\dots\dots (5)$$

The downstream pressure at which the region of constant acoustical efficiency (regime V) begins is calculated as follows:

$$p_{2CE} = \frac{p_1}{22 \alpha} \dots\dots\dots (6)$$

5.2 Regime definition

A control valve controls flow by converting potential (pressure) energy into turbulence. Noise in a control valve results from the conversion of a small portion of this energy into sound. Most of the energy is converted into heat.

The different regimes of noise generation are the result of differing sonic phenomena or reactions between molecules in the gas and the sonic shock cells. In regime I, flow is subsonic and the gas is partially recompressed, thus the involvement of the factor F_L . Noise generation in this regime is predominantly dipole.

In regime II, sonic flow exists with interaction between shock cells and with turbulent choked flow mixing. Recompression decreases as the limit of regime II is approached.

In regime III, no isentropic recompression exists. The flow is supersonic, and the turbulent flow-shear mechanism dominates.

In regime IV, the shock cell structure diminishes as a Mach disk is formed. The dominant mechanism is shock cell-turbulent flow interaction.

In regime V, there is constant acoustical efficiency; a further decrease in p_2 will result in no increase in noise.

For a given set of operating conditions, the regime is determined as follows:

Regime I	If $p_2 \geq p_{2C}$
Regime II	If $p_{2C} > p_2 \geq p_{vcc}$
Regime III	If $p_{vcc} > p_2 \geq p_{2B}$
Regime IV	If $p_{2B} > p_2 \geq p_{2CE}$
Regime V	If $p_{2CE} > p_2$

5.3 Preliminary calculations

5.3.1 Valve style modifier F_d

In the case of multistage valves, F_d applies only to the last stage.

The valve style modifier can be calculated by

$$F_d = \frac{d_H}{d_o} \dots\dots\dots (7a)$$

The hydraulic diameter d_H of a single flow passage is determined by the following equation:

$$d_H = \frac{4 A}{l_w} \dots\dots\dots (7b)$$

The equivalent circular diameter d_o of the total flow area is given as follows:

$$d_o = \sqrt{\frac{4 N_o A}{\pi}} \dots\dots\dots (7c)$$

Typical values of F_d are given in table 3.

5.3.2 Jet diameter D_j

The jet diameter is given by the following equation:

$$D_j = N_{14} F_d \sqrt{CF_L} \dots\dots\dots (8)$$

NOTE 1 N_{14} is a numerical constant, the values of which account for the specific flow coefficient (K_v or C_v) used. Values of the constant may be obtained from table 2.

NOTE 2 Use the required C , not the valve rated value of C .

NOTE 3 When the valve has attached fittings, replace F_L with F_{LP}/F_p .

5.3.3 Acoustic power ratio r_w

The acoustic power ratio represents the portion of sound power radiated into the downstream pipe. Factors for various valves and fittings are given in table 4.

Table 2 Numerical constants N

Constant	Flow coefficient	
	K_v	C_v
N_{14}	4.9×10^{-3}	4.6×10^{-3}
N_{14}	4.23×10^4	4.89×10^4
NOTE: Unlisted numerical constants are not used in this Standard.		

Table 3 Typical values of valve style modifier F_d (full size trim)

Valve type	Flow direction	Relative flow coefficient Φ					
		0.10	0.20	0.40	0.60	0.80	1.00
Globe, parabolic plug	To open	0.10	0.15	0.25	0.31	0.39	0.46
	To close	0.20	0.30	0.50	0.60	0.80	1.00
Globe, 3 V-port plug	Either ^{a)}	0.29	0.40	0.42	0.43	0.45	0.48
Globe, 4 V-port plug	Either ^{a)}	0.25	0.35	0.36	0.37	0.39	0.41
Globe, 6 V-port plug	Either ^{a)}	0.17	0.23	0.24	0.26	0.28	0.30
Globe, 60 equal diameter hole drilled cage	Either ^{a)}	0.40	0.29	0.20	0.17	0.14	0.13
Globe, 120 equal diameter hole drilled cage	Either ^{a)}	0.29	0.20	0.14	0.12	0.10	0.09
Butterfly, swing-through (centered shaft), to 70°	Either	0.26	0.34	0.42	0.50	0.53	0.57
Butterfly, fluted vane, to 70°	Either	0.08	0.10	0.15	0.20	0.24	0.30
Butterfly 60° flat disk	Either						0.50
Eccentric rotary plug	Either	0.12	0.18	0.22	0.30	0.36	0.42
Segmented ball 90°	Either	0.60	0.65	0.70	0.75	0.78	0.98
NOTE: These values are typical only; actual values are stated by the manufacturer.							
Note ^{a)} Limited $p_1 - p_2$ in flow to close direction.							

Table 4 Acoustic power ratio r_w

Valve or fitting	r_w
Globe, parabolic plug	0.25
Globe, 3 V-port plug	0.25
Globe, 4 V-port plug	0.25
Globe, 6 V-port plug	0.25
Globe, 60 equal diameter hole drilled cage	0.25
Globe, 120 equal diameter hole drilled cage	0.25
Butterfly, swing-through (centered shaft), to 70°	0.5
Butterfly, fluted vane, to 70°	0.5
Butterfly, 60° flat disk	0.5
Eccentric rotary plug	0.25
Segmented ball 90°	0.25
Expanders	1

5.4 Regime I (subsonic flow)

The velocity of the gas in the *vena contracta* is given by the following equation:

$$U_{vc} = \sqrt{2 \left(\frac{\gamma}{\gamma-1} \right) \left[1 - \left(\frac{p_{vc}}{p_1} \right)^{(\gamma-1)/\gamma} \right] \frac{p_1}{\rho_1}} \dots\dots\dots (9)$$

The stream power of the mass flow is calculated as follows:

$$W_m = \frac{\dot{m} (U_{vc})^2}{2} \dots\dots\dots (10)$$

The temperature in the *vena contracta* for subsonic flow is calculated from the following equation:

$$T_{vc} = T_1 \left(\frac{p_{vc}}{p_1} \right)^{(\gamma-1)/\gamma} \dots\dots\dots (11)$$

In the *vena contracta*, the speed of sound is calculated as follows:

$$c_{vc} = \sqrt{\frac{\gamma R T_{vc}}{M}} \dots\dots\dots (12)$$

The Mach number in the *vena contracta* is calculated using the following equation:

$$M_{vc} = \frac{U_{vc}}{c_{vc}} \dots\dots\dots (13)$$

For regime I, the acoustical efficiency factor is calculated as follows:

$$\eta_l = \left(1 \times 10^{-4} \right) M_{vc}^{3.6} \dots\dots\dots (14)$$

Thus, the sound power generated in regime I and radiated into the downstream pipe is

$$W_a = \eta_1 r_w W_m F_L^2 \dots\dots\dots (15)$$

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

Although not required for this method, the total internal sound power level is calculated as follows:

$$L_{wi} = 10 \log_{10} \frac{W_a}{W_o} \dots\dots\dots (16)$$

To calculate pipe internal sound power, subtract 6 dB from L_{wi} .

The peak frequency of the generated noise is calculated from the following equation:

$$f_p = \frac{0.2 U_{vc}}{D_j} \dots\dots\dots (17)$$

5.5 Regimes II to V (common calculations)

The following calculations are common for regimes II through V, which are at sonic velocity or above.

For sonic (or critical) flow, the *vena contracta* temperature is given by

$$T_{vcc} = \frac{2T_1}{\gamma + 1} \dots\dots\dots (18)$$

The velocity of sound in the *vena contracta* is calculated using the following equation:

$$c_{vcc} = \sqrt{\frac{\gamma R T_{vcc}}{M}} \dots\dots\dots (19)$$

Stream power is then calculated as follows:

$$W_{ms} = \frac{\dot{m} c_{vcc}^2}{2} \dots\dots\dots (20)$$

Although not required for this method, the internal sound power level is calculated using equation (16) and equations (23), (26), (28) or (32).

In the freely expanding jet, the Mach number is calculated from the following equation for regimes II through IV:

$$M_j = \sqrt{\frac{2}{\gamma - 1} \left[\left(\frac{p_1}{\alpha p_2} \right)^{(\gamma-1)/\gamma} - 1 \right]} \dots\dots\dots (21)$$

5.5.1 Regime II

The acoustical efficiency factor for regime II is calculated from the following equation:

$$\eta_2 = (1 \times 10^{-4}) M_j^{6.6 F_L^2} \dots\dots\dots (22)$$

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

The sound power generated in regime II and radiated into the downstream pipe is calculated as follows:

$$W_a = \eta_2 r_w W_{ms} \left(\frac{p_1 - p_2}{p_1 - p_{vcc}} \right) \dots\dots\dots (23)$$

The peak frequency is then determined as follows:

$$f_p = \frac{0.2 M_j c_{vcc}}{D_j} \dots\dots\dots (24)$$

5.5.2 Regime III

In regime III, the acoustical efficiency factor is calculated as follows:

$$\eta_3 = (1 \times 10^{-4}) M_j^{6.6 F_L^2} \dots\dots\dots (25)$$

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

The sound power generated in regime III and radiated into the downstream pipe is given by the following equation:

$$W_a = \eta_3 r_w W_{ms} \dots\dots\dots (26)$$

The peak frequency is calculated from equation (24).

5.5.3 Regime IV

The acoustical efficiency factor in regime IV is calculated as follows:

$$\eta_4 = (1 \times 10^{-4}) \left(\frac{M_j^2}{2} \right) (\sqrt{2})^{6.6 F_L^2} \dots\dots\dots (27)$$

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

The sound power generated in regime IV and radiated into the downstream pipe is then calculated from the following equation:

$$W_a = \eta_4 r_w W_{ms} \dots\dots\dots (28)$$

The peak frequency for regime IV is then determined as follows:

$$f_p = \frac{0.35 c_{vcc}}{1.25 D_j \sqrt{M_j^2 - 1}} \dots\dots\dots (29)$$

5.5.4 Regime V

In this regime, the jet Mach number is calculated from the following equation:

$$M_{j5} = \sqrt{\frac{2}{\gamma - 1} \left[(22)^{(\gamma-1)/\gamma} - 1 \right]} \dots\dots\dots (30)$$

The constant acoustical efficiency factor is determined as follows:

$$\eta_5 = \left[1 \times 10^{-4} \left(\frac{M_{j5}^2}{2} \right) (\sqrt{2})^{6.6 F_L^2} \right] \dots\dots\dots (31)$$

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

Then the sound power generated in regime V and radiated into the downstream pipe is calculated as follows:

$$W_a = \eta_5 r_w W_{ms} \dots\dots\dots (32)$$

The peak frequency for regime V is calculated from equation (29) using M_{j5} instead of M_j .

5.6 Noise calculations

The downstream mass density is calculated from the following equation:

$$\rho_2 = \rho_1 \left(\frac{p_2}{p_1} \right) \dots\dots\dots (33)$$

The downstream temperature T_2 may be determined by 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 .

From the following equation, the downstream sonic velocity can be calculated:

$$c_2 = \sqrt{\frac{\gamma R T_2}{M}} \dots\dots\dots (34)$$

The Mach number at the valve outlet is calculated using equation (35).

$$M_o = \frac{4 \dot{m}}{\pi D^2 \rho_2 c_2} \dots\dots\dots (35)$$

NOTE 1 M_o should not exceed 0.3. If M_o exceeds 0.3, then accuracy cannot be maintained, and the procedure in clause 7 should be used.

To calculate the internal sound-pressure level reference to P_o , the following equation is used:

$$L_{pi} = 10 \log_{10} \left[\frac{(3.2 \times 10^9) W_a \rho_2 c_2}{D_i^2} \right] \dots\dots\dots (36)$$

The transmission loss across the pipe wall is calculated as follows:

$$TL = 10 \log_{10} \left[(7.6 \times 10^{-7}) \left(\frac{c_2}{t_p f_p} \right)^2 \frac{G_x}{\left(\frac{\rho_2 c_2}{415 G_y} + 1 \right)} \left(\frac{p_a}{p_s} \right) \right] \dots\dots\dots (37)$$