BS EN 60534-8-3:2011

BSI Standards Publication

Industrial-process control valves

Part 8-3: Noise considerations — Control valve aerodynamic noise prediction method

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National foreword

This British Standard is the UK implementation of EN 60534-8-3:2011. It is identical to IEC 60534-8-3:2010. It supersedes BS EN 60534-8-3:2000 which will be withdrawn on 1 January 2014.

The UK participation in its preparation was entrusted by Technical Committee GEL/65, Measurement and control, to Subcommittee GEL/65/2, Elements of systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Industrial-process control valves - Part 8-3: Noise considerations - Control valve aerodynamic noise prediction method
(IEC 60534-8-3:2010)

Vannes de régulation des processus industriels -
Partie 8-3: Considérations sur le bruit -
Méthode de prédiction du bruit aérodynamique des vannes de régulation
(CEI 60534-8-3:2010)

Stellventile für die Prozessregelung -
Teil 8-3: Geräuschbetrachtungen -
Berechnungsverfahren zur Vorhersage der aerodynamischen Geräusche von Stellventilen
(IEC 60534-8-3:2010)

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Foreword

The text of document 65B/765/FDIS, future edition 3 of IEC 60534-8-3, prepared by IEC/SC 65B, Devices & process analysis, of IEC TC 65, Industrial-process measurement, control and automation, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60534-8-3 on 2011-01-01.

This European Standard supersedes EN 60534-8-3:2000.

The significant technical changes with respect to EN 60534-8-3:2000 are as follows:

– predicting noise as a function of frequency;

– using laboratory data to determine the acoustical efficiency factor.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2011-10-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2014-01-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60534-8-3:2010 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

[1] IEC 60534-2-1 NOTE Harmonized as EN 60534-2-1.

[2] IEC 60534-8-1 NOTE Harmonized as EN 60534-8-1.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60534	Series	Industrial-process control valves	EN 60534	Series
IEC 60534-1	-	Industrial-process control valves - Part 1: Control valve terminology and general considerations	EN 60534-1	-

CONTENTS

INTRODUCTION

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 IEC 60534-1 and IEC 60534-2-1.

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.

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 IEC 60534-8-1). The current edition has increased the level of confidence of the calculation. In some cases the results of the previous editions were more conservative.

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.

A rigorous analysis of the transmission loss equations is beyond the scope of this standard. The method considers the interaction between the sound waves existing in the pipe fluid and the first coincidence frequency in the pipe wall. In addition, 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.

Examples of calculations are given in Annex A.

This method is based on the IEC standards listed in Clause 2 and the references given in the Bibliography.

INDUSTRIAL-PROCESS CONTROL VALVES –

Part 8-3: Noise considerations – Control valve aerodynamic noise prediction method

1 Scope

This part of IEC 60534 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 from external surfaces or internally by pipe fittings, 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 (21) and (23) in 5.5).

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_pC exceeds 50 % of the rated flow coefficient.

For limitations on special low noise trims not covered by this standard, see Clause 8. 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

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60534 (all parts), *Industrial-process control valves*

IEC 60534-1, *Industrial-process control valves – Part 1: Control valve terminology and general considerations*

3 Terms and definitions

For the purposes of this document, all of the terms and definitions given in the IEC 60534 series and the following apply:

3.1
acoustical efficiency
η
ratio of the stream power converted into sound power propagating downstream to the stream power of the mass flow

3.2
external coincidence frequency
f_g
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
f_o
lowest frequency at which the internal 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
f_p
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

Symbol	Description	Unit
A	Area of a single flow passage	m^2
A_η	Valve correction factor for acoustical efficiency (see Table 4)	Dimensionless
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 IEC 60534-1)
c_a	External speed of sound (dry air at standard conditions = 343 m/s)	m/s
C_n	Flow coefficient for last stage of multistage trim with n stages	Various (see IEC 60534-1)
c_s	Speed of sound of the pipe (for steel = 5 000 m/s)	m/s
c_{vc}	Speed of sound in the *vena contracta* at subsonic flow conditions	m/s
c_{vcc}	Speed of sound in the *vena contracta* 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 *vena contracta*	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 (see Note 4)	Dimensionless
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 (see Note 4)	Dimensionless
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
f_s	Structural loss factor reference frequency = 1 Hz	Hz

Symbol	Description	Unit
G_x, G_y	Frequency factors (see Table 4)	Dimensionless
l	Length of a radial flow passage	m
l_w	Wetted perimeter of a single flow passage	m
L_g	Correction for Mach number	dB (ref p_o)
$L_{pe,1m}$ (f)	Frequency-dependent external sound-pressure level 1 m from pipe wall	dB(ref p_o)
$L_{pAe,1m}$	A-weighted overall sound-pressure level 1 m from pipe wall	dB(A) (ref p_o)
L_{pi}	Overall Internal sound-pressure level at pipe wall	dB (ref p_o)
L_{pi} (f)	Frequency-dependent internal sound-pressure level at pipe wall	dB (ref p_o)
L_{piR}	Overall Internal sound-pressure level at pipe wall for noise created by outlet flow in expander	dB (ref p_o)
L_{piR} (f)	Frequency-dependent internal sound-pressure level at pipe wall for noise created by outlet flow in expander	dB (ref p_o)
L_{piS} (f)	Combined internal frequency-dependent sound-pressure at the pipe wall, caused by the valve trim and expander	dB (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 *vena contracta*	Dimensionless
M_2	Mach number in downstream pipe	Dimensionless
$\dot{m}$	Mass flow rate	kg/s
N	Numerical constants (see Table 1)	Various
n_o	Number of independent and identical flow passages in valve trim	Dimensionless
p_a	Actual atmospheric pressure outside pipe	Pa (see Note 3)
p_n	Absolute stagnation pressure at inlet of the last stage of multistage valve with *n* stages	Pa
p_o	Reference sound pressure = 2×10^{-5} (see Note 5)	Pa
p_s	Standard atmospheric pressure (see Note 1)	Pa
p_{vc}	Absolute *vena contracta* pressure at subsonic flow conditions	Pa
p_1	Valve inlet absolute pressure	Pa
p_2	Valve outlet absolute pressure	Pa
R	Universal gas constant = 8 314	J/kmol × K
St	Strouhal number for peak frequency calculation (see Table 4)	Dimensionless

Symbol	Description	Unit
T_n	Inlet absolute temperature at last stage of multistage valve with *n* stages	K
T_{vc}	*Vena contracta* absolute temperature at subsonic flow conditions	K
T_{vcc}	*Vena contracta* absolute temperature at critical flow conditions	K
T_1	Inlet absolute temperature	K
T_2	Outlet absolute temperature	K
$TL(f)$	Frequency-dependent transmission loss	dB
t_s	Pipe wall thickness	m
U_p	Gas velocity in downstream pipe	m/s
U_R	Gas velocity in the inlet of diameter expander	m/s
W_a	Sound power for noise crated by valve flow and propagating downstream	W
W_{aR}	Sound power for noise generated by the outlet flow and propagating downstream	W
W_m	Stream power of mass flow	W
W_{ms}	Stream power of mass flow rate at sonic velocity	W
W_{mR}	Converted stream power in the expander	W
W_o	Reference sound power = 10^{-12} (see Note 5)	W
x	Differential pressure ratio	Dimensionless
x_{vcc}	*Vena contracta* differential pressure ratio at critical flow conditions	Dimensionless
x_B	Differential pressure ratio at break point	Dimensionless
x_C	Differential pressure ratio at critical flow conditions	Dimensionless
x_{CE}	Differential pressure ratio where region of constant acoustical efficiency begins	Dimensionless
α	Recovery correction factor	Dimensionless
β	Contraction coefficient for valve outlet or expander inlet	Dimensionless
γ	Specific heat ratio	Dimensionless
$\Delta L_A(f)$	A-Weighting correction based on frequency	dB
ΔTL	Damping factor for transmission loss	dB
η	Acoustical efficiency factor for noise created by valve flow (see Note 2)	Dimensionless
η_R	Acoustical efficiency factor for noise created by outlet flow in expander	Dimensionless
$\eta_s(f)$	Frequency-dependent structural loss factor	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
ρ_s	Density of the pipe	kg/m^3
Φ	Relative flow coefficient	Dimensionless

Symbol	**Description**	**Unit**
Subscripts		
e	Denotes external	
i	Denotes internal or used as an index for the frequency band number	
n	Denotes last stage of trim	
p	Denotes peak	
R	Denotes conditions in downstream pipe or pipe expander	

NOTE 1 Standard atmospheric pressure is 101,325 kPa or 1,01325 bar.

NOTE 2 Subscripts 1, 2, 3, 4 and 5 denote regimes I, II, III, IV and V respectively.

NOTE 3 1 bar = 10^2 kPa = 10^5 Pa.

NOTE 4 For the purpose of calculating the *vena contracta* pressure, and therefore velocity, in this standard, pressure recovery for gases is assumed to be identical to that of liquids.

NOTE 5 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 Valves 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. For noise considerations related to control valves the differential pressure ratio x is often used.

$$x = \frac{p_1 - p_2}{p_1} \tag{1}$$

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

$$\frac{p_{vc}}{p_1} = 1 - \frac{x}{F_L^{\ 2}} \tag{2}$$

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

NOTE 2 When the valve has attached fittings, F_L should be replaced 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* and the corresponding differential pressure ratio when $p_2 = p_{vcc}$ are calculated as follows:

$$x_{vcc} = 1 - \left(\frac{2}{\gamma + 1}\right)^{\gamma/(\gamma-1)} \tag{3}$$

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

$$x_C = F_L^{\ 2}\, x_{vcc} \tag{4}$$

NOTE 4 When the valve has attached fittings, F_L should be replaced 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:

$$\alpha = \frac{1 - x_{vcc}}{1 - x_C} \tag{5}$$

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 differential pressure ratio at the break point is calculated as follows:

$$x_B = 1 - \frac{1}{\alpha}\left(\frac{1}{\gamma}\right)^{\gamma/(\gamma-1)} \tag{6}$$

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

$$x_{CE} = 1 - \frac{1}{22\,\alpha} \tag{7}$$

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, the 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			$x \le x_C$
Regime II	If	x_C	$<$	$x \le x_{vcc}$

Regime III	If	x_{vcc}	$<$	$x \leq x_B$
Regime IV	If	x_B	$<$	$x \leq x_{CE}$
Regime V	If	x_{CE}	$<$	x

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

$$F_d = \frac{d_H}{d_o} \tag{8a}$$

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

$$d_H = \frac{4\ A}{l_w} \tag{8b}$$

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

$$d_o = \sqrt{\frac{4 \cdot n_o \cdot A}{\pi}} \tag{8c}$$

Typical values of F_d are given in Table 2.

5.3.2 Jet diameter D_j

The jet diameter is given by the following equation:

$$D_j = N_{14}\ F_d \sqrt{C\ F_L} \tag{9}$$

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 1.

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

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

5.3.3 Inlet fluid density ρ_1

Whenever possible it is preferred to use the actual fluid density as specified by the user. If this is not available, then a perfect gas is assumed, and the inlet density is calculated from the following equation:

$$\rho_1 = \frac{p_1}{RT_1} \tag{10}$$

Table 1 – Numerical constants *N*

Constant	Flow coefficient	
	K_v	C_v
N_{14}	$4{,}9 \times 10^{-3}$	$4{,}6 \times 10^{-3}$
N_{16}	$4{,}23 \times 10^{4}$	$4{,}89 \times 10^{4}$
NOTE Unlisted numerical constants are not used in this standard.		

Table 2 – 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*	0,29	0,40	0,42	0,43	0,45	0,48
Globe, 4 V-port plug	Either*	0,25	0,35	0,36	0,37	0,39	0,41
Globe, 6 V-port plug	Either*	0,17	0,23	0,24	0,26	0,28	0,30
Globe, 60 equal diameter hole drilled cage	Either*	0,40	0,29	0,20	0,17	0,14	0,13
Globe, 120 equal diameter hole drilled cage	Either*	0,29	0,20	0,14	0,12	0,10	0,09
Butterfly, eccentric	Either	0.18	0.28	0.43	0.55	0.64	0.70
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
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.							
* Limited $p_1 - p_2$ in flow to close direction.							

5.4 Internal noise calculations

5.4.1 Calculations common to all regimes

In each regime, the internal acoustic power W_a is equal to the product of the stream power W_m and the acoustical efficiency factor η, as shown in Equation 11.

$$W_a = \eta W_m \tag{11}$$

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

$$L_{wi} = 10 \log_{10} \frac{W_a}{W_o} \tag{12}$$

5.4.2 Regime dependent calculations

The equations to calculate the appropriate values of W_m and η are given in Table 3 for each regime. This allows the internal acoustic power W_a to be determined, using Equation (11).

Table 3 – Overview of regime dependent equations

Regime	Mach number M_{vc}, M_j, M_{j5}	η	f_p	T_{vc}, T_{vcc}	c_{vc}, c_{vcc}	W_m
I subsonic $x \le x_C$	$M_{vc} = \sqrt{\left(\frac{2}{\gamma - 1}\right)\left[\left(1 - \frac{x}{F_L^2}\right)^{(1-\gamma)/\gamma} - 1\right]}$	$\eta = \left(1 \times 10^{A_\eta}\right) F_L^2 \cdot M_{vc}^3$	$f_p = \frac{St_p \cdot M_{vc} \cdot c_{vc}}{D_j}$	$T_{vc} = T_1 \left(1 - \frac{x}{F_L^2}\right)^{(\gamma-1)/\gamma}$	$c_{vc} = \sqrt{\gamma \frac{p_1}{\rho_1}\left(1 - \frac{x}{F_L^2}\right)^{(\gamma-1)/\gamma}}$	$W_m = \frac{\dot{m}\left(M_{vc} c_{vc}\right)^2}{2}$
II $x_C < x \le x_{vcc}$	$M_j = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{1}{\alpha\,(1\text{-x})}\right)^{(\gamma-1)/\gamma} - 1\right]}$	$\eta = \left(1 \times 10^{A_\eta}\right) \cdot \frac{x}{x_{vcc}} M_j^{6,6 F_L^2}$	$f_p = \frac{St_p \cdot M_j \cdot c_{vcc}}{D_j}$	$T_{vcc} = \frac{2\,T_1}{\gamma + 1}$	$c_{vcc} = \sqrt{\frac{2\gamma}{\gamma + 1}\frac{p_1}{\rho_1}}$	$W_m = \frac{\dot{m}\, c_{vcc}^2}{2}$
III $x_{vcc} < x \le x_B$	$M_j = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{1}{\alpha\,(1\text{-x})}\right)^{(\gamma-1)/\gamma} - 1\right]}$	$\eta = \left(1 \times 10^{A_\eta}\right) \cdot M_j^{6,6 F_L^2}$	$f_p = \frac{St_p \cdot M_j \cdot c_{vcc}}{D_j}$			
IV $x_B < x \le x_{CE}$	$M_j = \sqrt{\frac{2}{\gamma - 1}\left[\left(\frac{1}{\alpha\,(1\text{-x})}\right)^{(\gamma-1)/\gamma} - 1\right]}$	$\eta = \left(1 \times 10^{A_\eta}\right)\left(\frac{M_j^2}{2}\right)\left(\sqrt{2}\right)^{6,6 F_L^2}$	$f_p = \frac{1.4 \cdot St_p \cdot c_{vcc}}{D_j \sqrt{M_j^2 - 1}}$			
V $x_{CE} \le x$	$M_{j5} = \sqrt{\frac{2}{\gamma - 1}\left[(22)^{(\gamma-1)/\gamma} - 1\right]}$	$\eta = \left(1 \times 10^{A_\eta}\right)\left(\frac{M_{j5}^2}{2}\right)\left(\sqrt{2}\right)^{6,6 F_L^2}$	$f_p = \frac{1.4 \cdot St_p \cdot c_{vcc}}{D_j \sqrt{M_{j5}^2 - 1}}$			

NOTE When the valve has attached fittings, F_L should be replaced with F_{LP}/F_p.

The exponent A_η is – 4 for pure dipole noise sources as for free jets in a big expansion volume. The valve-related acoustic efficiency factor takes into account the effect of different geometries of valve body and fittings on the acoustical efficiency and the location inside the pipe behind the control valve (distance 6 x d_i). Hence, real A_η factors are different for various valves and fittings. Also this value can be dependent on the differential pressure ratio x. Typical average values are given in Table 4.

The Strouhal number St_p at the peak frequency lies typically in a range of 0,1 through 0,3 for free jets. Typical average values for different various valves and fittings are given in Table 4.

Table 4 – Typical values of A_η and St_p

Valve or fitting	*Flow direction*	A_η	St_p
Globe, parabolic plug	Either	-4,2	0,19
Globe, V-port plug	Either	-4,2	0,19
Globe, ported cage design	Either	-3,8	0,2
Globe, multihole drilled plug or cage	To open	-4,8	0,2
Globe, multihole drilled plug or cage	To close	-4,4	0,2
Butterfly, eccentric	Either	-4,2	0,3
Butterfly, swing-through (centered shaft), to 70°	Either	-4,2	0,3
Butterfly, fluted vane, to 70°	Either	-4,2	0,3
Butterfly, 60° flat disk	Either	-4,2	0,3
Eccentric rotary plug	Either	-3,6	0,3
Segmented ball 90°	Either	-3,6	0,3
Drilled hole plate fixed resistance	Either	-4,8	0,2
Expander	Either	-3,0	0,2

NOTE 1 These values are typical only. Actual values are stated by the manufacturer.

NOTE 2 Section 8 should be used, for those multihole trims, where the hole size and spacing is controlled to minimize noise.

5.4.3 Downstream calculations

The downstream mass density is calculated from the following equation, assuming T_1=T_2:

$$\rho_2 = \rho_1 \left(\frac{p_2}{p_1} \right) \tag{13}$$

The downstream temperature T2 may be determined by using thermodynamic isenthalpic relationships, provided that the necessary fluid properties are known. However, if the fluid properties are not known, T2 may be taken as approximately equal to T1. From the following equation, the downstream sonic velocity can be calculated:

$$c_2 = \sqrt{\frac{\gamma R T_2}{M}} \tag{14}$$

The Mach number at the valve outlet is calculated using Equation (15).

$$\mathrm{M}_o = \frac{4\,\dot{\mathrm{m}}}{\pi\,\mathrm{D}^2\,\rho_2\,\mathrm{c}_2} \tag{15}$$

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.

The downstream pipe velocity correction is approximately:

$$L_g = 16\log_{10}\left(\frac{1}{1-M_2}\right) \tag{16}$$

where

$$M_2 = \frac{4\,\dot{m}}{\pi\,D_i^2\,\rho_2\,c_2} \tag{17}$$

NOTE 2 For calculating L_g, M_2 is limited to 0,3.

5.4.4 Valve internal sound pressure calculation at pipe wall

To calculate the internal sound-pressure level referenced to p_o, the following equation is used:

$$\mathrm{L}_{pi} = 10\,log_{10}\left[\frac{\left(3{,}2\times10^9\right)\mathrm{W}_a\,\rho_2\,\mathrm{c}_2}{\mathrm{D}_i^{\,2}}\right] + L_g \tag{18}$$

The frequency dependent internal sound pressure levels can be predicted from Equation (39) ([17]).

$$\mathrm{L}_{pi}(f_i) = \mathrm{L}_{pi} - 8 - 10\cdot\log\left\{\left[1+\left(\frac{f_i}{2\cdot f_p}\right)^{2.5}\right]\cdot\left[1+\left(\frac{f_p}{2\cdot f_i}\right)^{1.7}\right]\right\} \tag{19}$$

Table 5 – Indexed frequency bands

Index	1	2	3	4	5	6	7	8	9	10	11
Frequency [Hz]	12,5	16	20	25	31,5	40	50	63	80	100	125
Index	12	13	14	15	16	17	18	19	20	21	22
Frequency [Hz]	160	200	250	315	400	500	630	800	1000	1250	1600
Index	23	24	25	26	27	28	29	30	31	32	33
Frequency [Hz]	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000

NOTE 1 The constant –8 replaces the original constant –5,3 so that the overall level – L_{pi} for more than 21 octaves becomes 0.

NOTE 2 Equation (19) should not be used outside of the frequency range (12,5 Hz – 20 000 Hz) as indicated in Table 5.

5.5 Pipe transmission loss calculation

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

$$\mathrm{TL}(f_i) = 10\,log_{10}\left[\left(8{,}25\times10^{-7}\right)\left(\frac{c_2}{t_S f_i}\right)^2 \frac{G_x(f_i)}{\left(\dfrac{\rho_2\, c_2 + 2\cdot\pi\cdot t_S\cdot f_i\cdot\rho_s\cdot\eta_s(f_i)}{415\,G_y(f_i)}+1\right)}\left(\frac{p_a}{p_s}\right)\right] - \Delta TL \tag{20a}$$

where ΔTL is a damping factor depending on the pipe size:

$$\Delta TL = \begin{cases} 0 & for\ D > 0{,}15 \\ -16660\cdot D^3 + 6370\cdot D^2 - 813\cdot D + 35{,}8 & for\ 0{,}05 \le D \le 0{,}15 \\ 9 & for\ D < 0{,}05 \end{cases} \tag{20b}$$

and η_s is the non-dimensional frequency-dependent structural loss factor:

$$\eta_s(f_i) = \sqrt{\frac{f_s}{100 f_i}} \tag{20c}$$

NOTE 1 G_x and G_y are defined in Table 6.

NOTE 2 The ratio p_a/p_s is a correction for local barometric pressure.

The frequencies f_r, f_o and f_g are calculated from the following equations:

$$f_r = \frac{c_s}{\pi D_i} \tag{21}$$

$$f_o = \frac{f_r}{4}\left(\frac{c_2}{c_a}\right) \tag{22}$$

$$f_g = \frac{\sqrt{3}\,(c_a)^2}{\pi\, t_S (c_s)} \tag{23}$$

NOTE 3 In Equations (22) and (23), c_a = 343 m/s for the speed of sound of dry air at standard conditions.

NOTE 4 In Equations (21) and (23), c_s = 5 000 m/s for the nominal speed of sound in the pipe wall if made of steel.

NOTE 5 It should be noted that the minimum transmission loss occurs at the first pipe coincidence frequency.

Table 6 – Frequency factors G_x (f) and G_y (f)

$f_i < f_o$	$f_i \geq f_o$
$G_x(f_i) = \left(\frac{f_o}{f_r}\right)^{2/3} \left(\frac{f_i}{f_o}\right)^4$	$G_x(f_i) = \left(\frac{f_i}{f_r}\right)^{1/2}$ for $f_i < f_r$ $G_x(f_i) = 1$ for $f_i \geq f_r$
$G_y(f_i) = \left(\frac{f_o}{f_g}\right)$ for $f_o < f_g$ $G_y(f_i) = 1$ for $f_o \geq f_g$	$G_y(f_i) = \left(\frac{f_i}{f_g}\right)$ for $f_i < f_g$ $G_y(f_i) = 1$ for $f_i \geq f_g$

5.6 External sound pressure calculation

The external sound pressure level spectrum at a distance of 1 m from the pipe wall can be calculated from the internal sound-pressure level spectrum and the transmission losses. For higher valve outlet Mach numbers the combined internal sound-pressure $L_{piS(fi)}$ at the pipe wall caused by valve trim and expander instead of $L_{pi(fi)}$ shall be used (see Equation (43) in Clause 7).

$$L_{pe,1m}(f_i) = L_{pi}(f_i) + TL(f_i) - 10 \log\left(\frac{D_i + 2\,t_S + 2}{D_i + 2\,t_S}\right) \tag{24}$$

Finally, the overall A-weighted sound pressure level at a distance of 1 m from the pipe wall can be calculated by:

$$L_{pAe,1m} = 10 \cdot Log_{10}\left(\sum_{i=1}^{N=33} 10^{\frac{L_{pe,1m}(f_i) + \Delta L_A(f_i)}{10}}\right) \tag{25}$$

where

f_i = third octave band center frequency;

$L_{pi}(f_i)$ = internal sound pressure level at frequency f_i ;

$TL(f_i)$ = transmission loss at frequency f_i ;

$\Delta L_A(f_i)$ = “A” weighting factor at frequency f_i.

Table 7 – "A" weighting factor at frequency f_i

f_i [Hz}	12,5	16	20	25	31.5	40	50	63	80	100	125
$\Delta L_A(f_i)$	-63,4	-56,7	-50,5	-44,7	-39,4	-34,6	-30,2	-26,2	-22,5	-19,1	-16,1
f_i [Hz}	160	200	250	315	400	500	630	800	1000	1250	1600
$\Delta L_A(f_i)$	-13,4	-10,9	-8,6	-6,6	-4,8	-3,2	-1,9	-0,8	0	0,6	1,0
f_i [Hz}	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
$\Delta L_A(f_i)$	1,2	1,3	1,2	1,0	0,5	-0,1	-1,1	-2,5	-4,3	-6,6	-9,3

NOTE Octave bands can be also used, when in Equation (19) instead of the first term of 8 dB, a value of 3 dB is used.

5.7 Calculation flow chart

The following flow chart provides a logical sequence for using the above equations to calculate the sound-pressure level.

Start with 5,1, 5,2 and 5,3 for all regimes

Then 5,4 for regime dependent calculations

Then 5,5 and 5,6 for all regimes.

NOTE See Annex A for calculation examples.

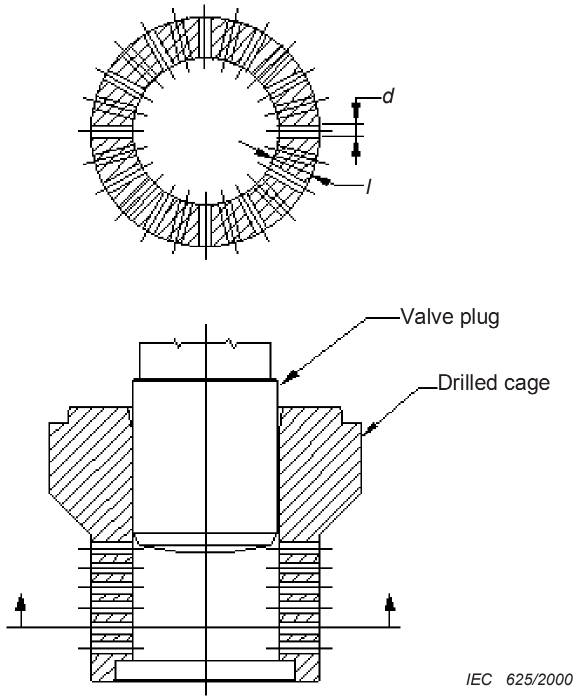
6 Valves with special trim design

6.1 General

This clause is applicable to valves with special trim design. Although it uses much of the procedure from Clause 5, it is placed in a separate clause of this standard, because these trims need special consideration.

6.2 Single stage, multiple flow passage trim

For valves with single stage, multiple flow passage trim (see Figure 1 for one example of many effective noise reducing trims) without significant pressure recovery between stages, the procedure in Clause 5 shall be used, except as noted below.



NOTE This is one example of many effective noise-reducing trims.

Figure 1 – Single stage, multiple flow passage trim

All flow passages shall have the same hydraulic diameter, and the distance between them shall be sufficient to prevent jet interaction.

Although the valve style modifier is the same as in Clause 5, an example of its application is given below:

EXAMPLE

Assume a trim with 48 exposed rectangular passages which have a width of 0,010 m and a height of 0,002 m. The area A of each passage is 0,010 × 0,002 = 0,000 02 m^2. The wetted perimeter

l_W = (2 × 0,010) + (2 × 0,002) = 0,024 m; d_o = 0,035 m, and d_H = 0,0033, which yields F_d = 0,0033/0,035 = 0,094.

The jet diameter D_j is calculated as follows:

$$D_j = N_{14} \cdot F_d \sqrt{C\left[0,9 - 0,06\left(l/d\right)\right]} \qquad (26)$$

NOTE 1 F_{Ln} has been replaced by [0,9 – 0,06(l/d)] in the expression for D_j, and l/d has a maximum value of 4.

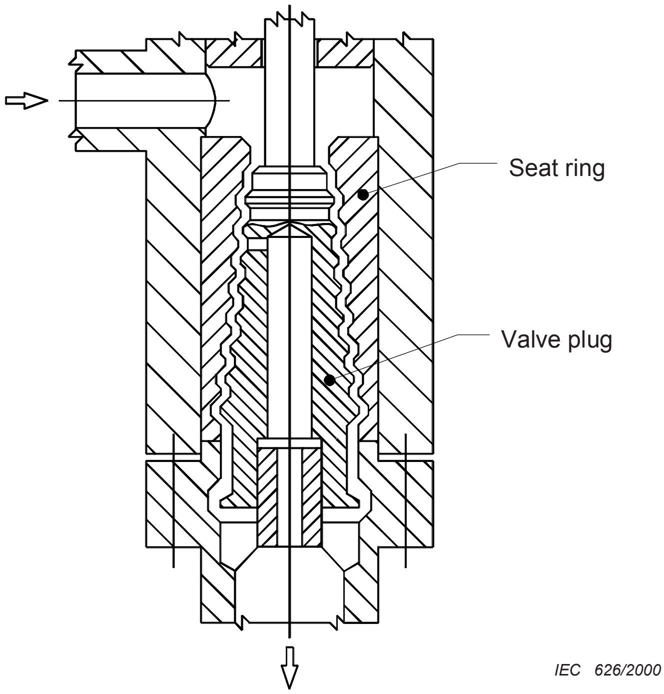
The result of using [0,9 – 0,06(l/d)] instead of F_{Ln} is a general increase in the transmission loss in regimes I, II and III by up to 5 dB.

The Mach number at the valve outlet is calculated using Equation (15).

NOTE 2 For pressure ratios p_1/p_2 > 4, Equation (8a), which is used to calculate F_d, is only applicable when the wall distance between passages exceeds 0,7 d. It also loses its validity if the Mach number M_o at the valve outlet exceeds 0,2.

6.3 Single flow path, multistage pressure reduction trim (two or more throttling steps)

For single flow path, multistage valves (see Figure 2 for one example of many effective noise-reducing trims) without significant pressure recovery between stages, the procedure of Clause 5 shall be used, except as noted below.



NOTE This is one example of many effective noise-reducing trims.

Figure 2 – Single flow path, multistage pressure reduction trim

NOTE 1 All calculations in 6.3 are applicable to the last stage.

The flow coefficient C_n shall be used in place of C. It is applicable to the last stage of the multistage trim. When values of C_n are not available from the valve manufacturer, the following relationship shall be used:

$$C_n = N_{16}\, A_n \tag{27}$$

NOTE 2 N_{16} is a numerical constant, the value of which accounts for the specific flow coefficient (K_v or C_v) used. Values of the constants may be obtained from Table 1.

The stagnation pressure p_n at the last stage shall be used in place of p_1, and the density ρ_n shall be used in place of ρ_1. These values are determined using the following equations as appropriate:

NOTE 3 If $p_1/p_2 \geq 2$, then it should first assumed that $p_n/p_2 < 2$ and p_n should then be calculated from Equation (28a). If the calculated $p_n \geq 2\, p_2$, then p_n should be calculated from Equation (28b) and the procedure continued.

If $p_1/p_2 \geq 2$ and $p_n/p_2 < 2$:

$$p_n = \sqrt{\left(\frac{p_1\, C}{1{,}155\, C_n}\right)^2 + {p_2}^2} \tag{28a}$$

If $p_1/p_2 \geq 2$ and $p_n/p_2 \geq 2$:

$$p_n = p_1\left(\frac{C}{C_n}\right) \tag{28b}$$

If $p_1/p_2 < 2$:

$$p_n = \sqrt{\left(\frac{C}{C_n}\right)^2 \left(p_1^{\,2} - p_2^{\,2}\right) + p_2^{\,2}} \tag{28c}$$

$$\rho_n = \rho_1 \left(\frac{p_n}{p_1}\right) \tag{29}$$

The jet diameter for the last stage used in the equations for the peak frequency is determined from the following equation:

$$D_j = N_{14}\, F_d \sqrt{C_n\, F_L} \tag{30}$$

NOTE 4 For this Equation, F_d and F_L of the last stage should be used.

Finally, the internal sound pressure level of the last stage that is radiated into the pipe has to be corrected with the following equation:

$$L_{pi} = L_{pi,n} + \frac{1}{(n-1)^{0.125}}\, 10 \cdot \log_{10}\left(\frac{p_1}{p_n}\right) \tag{31}$$

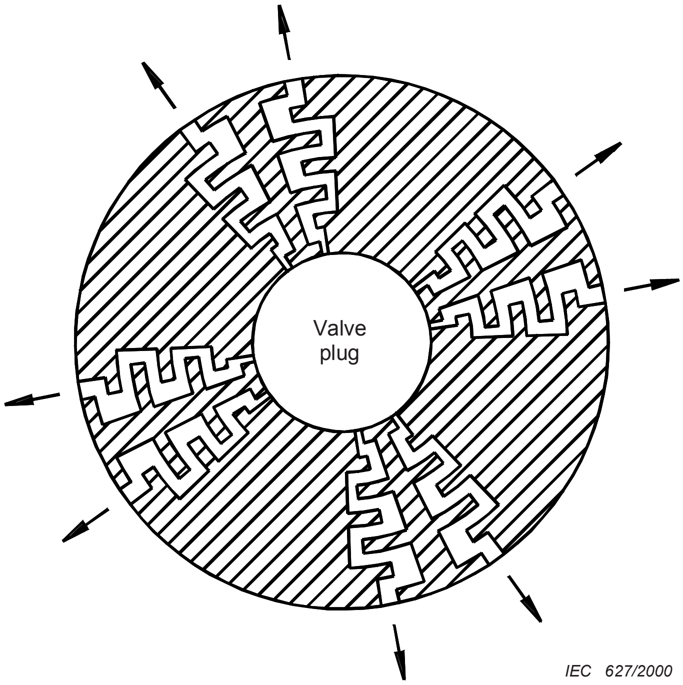
NOTE 5 The noise contribution of the last stage is given by $L_{pi,n}$. The term 10 $\log_{10}$ (p_1/p_n) includes the sound pressure level caused by the pressure reductions of the other stages.

6.4 Multipath, multistage trim (two or more passages and two or more stages)

NOTE 1 This subclause covers only linear travel valves.

NOTE 2 All calculations in 6.4 are applicable to the last stage.

For multipath, multistage trim (see Figure 3 for one example of many effective noise-reducing trims), the procedure of Clause 5 shall be used, except as noted below.



NOTE This is one example of many effective noise-reducing trims.

Figure 3 – Multipath, multistage trim (two or more passages and two or more stages)

All flow passages shall have the same hydraulic diameter, and the distance between them shall be sufficient to prevent jet interaction. The flow area of each stage shall increase between inlet and outlet.

The *vena contracta* pressure p_{vc} shall be calculated using F_{Ln} instead of F_L in Equation (2). The flow coefficient C_n per Equation (27) shall be used in place of C; the stagnation pressure p_n of the last stage per Equation (28) shall be used in place of p_1; and the density ρ_n per Equation (29) shall be used in place of ρ_1.

The jet Mach number is calculated from the following equation:

$$M_{jn} = \sqrt{\left(\frac{2}{\gamma - 1}\right)\left[\left(1 - \frac{x}{F_{Ln}^{\ 2}}\right)^{(1-\gamma)/\gamma} - 1\right]} \qquad (32)$$

where the pressure drop ratio x for the last stage is determined from Equation (1) using p_n in place of p_1.

The peak frequency f_p is calculated from Equation (33) using the jet diameter D_j for the last stage from Equation (30):

$$f_p = \frac{\mathrm{St}_p\, M_{jn}\, c_{vc}}{D_j} \qquad (33)$$

NOTE 3 If the Strouhal number St_p cannot be determined, St_p can be set to equal 0,2.

NOTE 4 The method of 6.4 is not accurate if the Mach number M_o at the valve outlet exceeds 0,2. For calculation of M_o, see Equation (15). At a Mach number of 0,3, errors may exceed 5 dB. Refer to Clause 7 for the procedure for higher Mach numbers.

NOTE 5 See Annex A for a calculation example.

Finally, the A-weighted sound-pressure level L_{pAe} is calculated using Equation (25).

7 Valves with higher outlet Mach numbers

7.1 General

This clause provides a method for predicting sound pressure levels produced at the outlet of the valve with or without an expander. The applicability is limited to 30° as total angle of the transition piece installed downstream of the valve. Higher angles can lead to flow instabilities that are not within the scope of this standard.

7.2 Calculation procedure

In the downstream pipe, the velocity is limited to a Mach number of 0,8 and is calculated from the following equation:

$$U_p = \frac{4\,\dot{m}}{\pi\,\rho_2\,D_i^2} \tag{34}$$

The gas velocity U_R at the inlet of the expander is limited to the sonic velocity c_2 and is calculated as follows:

$$U_R = \frac{U_p\,D_i^2}{\beta\,d_i^2} \tag{35}$$

NOTE 1 It is recognized that the velocity profile in the valve outlet is not uniform in all cases, and a contraction coefficient may have to be employed. This coefficient β is included in Equation (35). The value of β can be derived from test data using the point of choked flow in the valve outlet as an indication of Mach 1. Net area equals mass flow divided by density and speed of sound. It can also be determined by analytical methods. A value of β = 0,93 seems to be applicable to straight pattern globe valves. Data for other valve styles are not available at this time, but for some rotary valves the value may be as low as 0,7.

The stream power in the expander is determined from Equation (36).

$$W_{mR} = \frac{\dot{m}\,U_R^2}{2}\left[\left(1-\frac{d_i^2}{D_i^2}\right)^2 + 0{,}2\right] \tag{36}$$

The peak frequency of the generated noise is determined as follows:

$$f_{pR} = \frac{St_p\ U_R}{d_i} \tag{37}$$

Equation (38) is used to calculate the acoustical efficiency factor.

$$\eta_R = \left(1 \times 10^{A_\eta}\right) M_R^{\ 3} \tag{38}$$

NOTE 2 For St_p and A_η s. Table 4 where

$$M_R = \frac{U_R}{c_2} \tag{39}$$

Then, the generated sound power is determined as follows:

$$W_{aR} = \eta_R \, W_{mR} \tag{40}$$

Although not required for this method, the total sound power level is calculated using Equation (12).

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

$$L_{piR} = 10\,log_{10}\left[\frac{\left(3{,}2 \times 10^9\right) W_{aR}\,\rho_2\,c_2}{D_i^{\,2}}\right] + L_g \tag{41}$$

The frequency spectrum related to the internal sound pressure levels due to the downstream pipe noise can be predicted from Equation (42) ([17]).

$$L_{piR}(f_i) = L_{piR} - 8 - 10\cdot\log\left\{\left[1+\left(\frac{f_i}{2\cdot f_{pR}}\right)^{2.5}\right]\cdot\left[1+\left(\frac{f_{pR}}{2\cdot f_i}\right)^{1.7}\right]\right\} \tag{42}$$

NOTE 3 Octave bands can be also used, when in Equation (41) instead of the first term of 8 dB, a value of 3 dB is used

The combined sound-pressure level $L_{piS}(f_i)$ from both the valve trim $L_{pi}(f_i)$ and the expander $L_{piR}(f_i)$ can be estimated from Equation (42).

$$L_{piS}(f_i) = 10\,log_{10}\left(10^{L_{pi}(f_i)/10} + 10^{L_{piR}(f_i)/10}\right) \tag{43}$$

$L_{pis}(f_i)$ has then to be used instead $L_{pi}(f_i)$ in Equation (24) to calculate the external sound pressure levels in Equations (24) and (25).

8 Valves with experimentally determined acoustical efficiency factors

This standard recognizes acoustical efficiency factors based on laboratory data for specific valve designs as an alternative to the values calculated using the typical values given in Table 4. This alternative value of the acoustical efficiency factor η_x shall be calculated from noise measurements according to procedures in IEC 60534-8-1.

The preferred method is that L_{pi} *and* $L_{pi}(f_i)$ are measured versus the differential pressure ratio x directly according to IEC 60534-8-1 Method B.

An alternative is that $L_{pe,1m}$ *and* $L_{pe,1m}(f_i)$ are measured from external noise measurements vs. the differential pressure ratio x according to the procedures given in IEC 60534-8-1 Method A. On that basis, L_{pi} *and* $L_{pi}(f_i)$ have to be calculated from the measured $L_{pe,1m}(f_i)$and the transmission loss (see 5.6).Therefore the pipe data of the test facility shall be used.

For both measurements the valve outlet Mach number M_O should be lower than the appropriate limits for the trim being tested.

On the basis of the experimentally determined L_{pi} *and* $L_{pi}(f_i)$ (direct or via $L_{pe,1m}(f_i)$), the following parameters may be determined:

- The experimentally determined acoustical efficiency factor η_x as a function of *x*. This would be used in place of the values calculated according to the equations in Table 3.
- A new frequency profile function $L_{pi}(f_i) - L_{pi}$, from which new values of the peak Strouhal number may be determined. The new profile would be used in place of Equation (19). The new Strouhal number would be used in place of the typical values that are given in Table 4 when calculating the peak frequency f_p according to the equations in Table 3.

All other calculations should be in accordance with 5.7.

9 Combination of noise produced by a control valve with downstream installed two or more fixed area stages

When fixed area pressure reduction stages (like drilled holes plates) are installed downstream a control valve, total noise produced downstream can be calculated as follows (the example refers to a two-stage configuration):

$$L_{piTot}(fi) = 10 \bullet \log_{10}\left(10^{0.1 \bullet (Lpi(1)(fi) - \Delta(2)(fi) - \Delta(3)(fi))} + 10^{0.1 \bullet (Lpi(2)(fi) - \Delta(3)(fi))} + 10^{0.1 \bullet (Lpi(3)(fi))}\right) \quad (44)$$

where

- $L_{piTOT}(f_i)$ is the total noise level inside the pipe downstream the last fixed area stage. $L_{piTOT}(f_i)$ shall be used in Equation (24) instead of $Lpi(fi)$ to calculate $L_{pe,1m}(f_i)$;
- $L_{pi(j)}(f_i)$ is the internal noise level produced by the stage *(j)* at the frequency (f_i) into the downstream pipe without taking in account downstream installed silencer attenuation;
- $\Delta_{(j)}(f_i)$ is the noise attenuation of the stage *(j)* at the frequency (f_i). $\Delta_{(j)}(f_i)$ are experimental values. If no experimental values are available $\Delta_{(j)}(f_i)$ can be set 0.

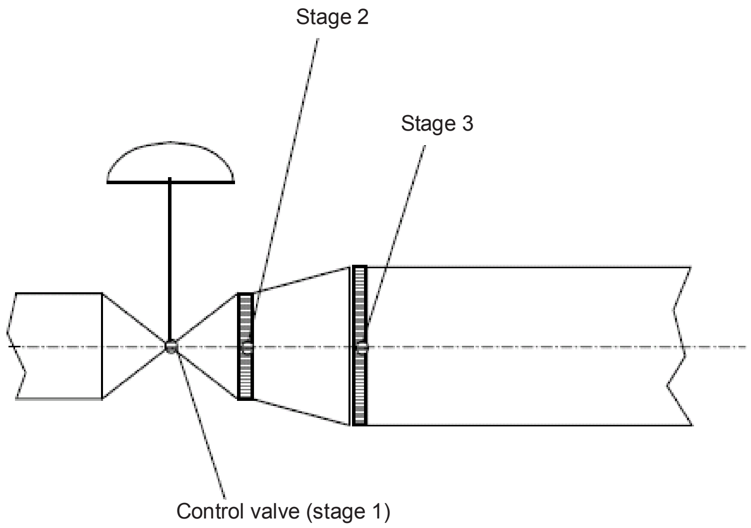


Figure 4 – Control valve with downstream installed two fixed area stages

Annex A
(informative)

Calculation examples

A.1 General

This annex indicates how the equations in this standard are used. The use of calculated values to several significant places is not meant to imply such accuracy; it is only to assist the user in checking the calculated values. The numbers on the left-hand side in parentheses are the equation numbers as used in this standard.

A.2 Calculation examples 1 to 6

Given data

Valve

Single-seat globe valve (with cage) installed flow to open

Valve size:	*Various*
Valve outlet diameter:	*Various*
Rated C_v:	C_{vR} = 195
Required C_v:	*Various*
Combined liquid pressure recovery factor and piping geometry factor:	F_{LP} = 0,792
Number of cage openings:	N_O = 6
Wetted perimeter of single flow passage:	l_W = 181 mm = 0,181 m
Area of single flow passage:	A = 0,00137 m^2
Pressure drop ratio factor:	x_T = 0,75

Pipe

Inlet nominal pipe size:	DN 200
Outlet nominal pipe size:	DN 200
Pipe wall thickness:	t_S = 8 mm = 0.008 m
Internal pipe diameter:	*Various*
Speed of sound in pipe:	c_S = 5 000 m/s
Density of pipe material:	ρ_S = 8 000 kg/m^3

Other

Speed of sound in air:	c_o = 343 m/s
Density of air:	ρ_o = 1,293 kg/m^3
Actual atmospheric pressure:	p_a = 1,013 25 bar = 1,013 25 × 10^5 Pa

Standard atmospheric pressure: p_s = 1,013 25 bar = 1,013 25 × 10^5 Pa

The following values are used in, or determined from, calculations based on IEC 60534-2-1.

Head loss coefficient: $\Sigma\zeta$ = 0,86

Sum of inlet velocity head coefficient: ζ_i = 1,2

Piping geometry factor: F_p = 0,98

Table A.1 – Calculation: examples 1 to 6

	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
Type fluid: vapour						
Mass flow rate	$\dot{m}$ = 2.22 kg/s	$\dot{m}$ = 2.29 kg/s	$\dot{m}$ = 2.59 kg/s	$\dot{m}$ = 1.18 kg/s	$\dot{m}$ = 1.19 kg/s	$\dot{m}$ = 0.89 kg/s
Valve inlet absolute pressure	p_1 = 10 bar = 1.0 x 10^6 Pa	p_1 = 10 bar = 1.0 x 10^6 Pa	p_1 = 10 bar = 1.0 x 10^6 Pa	p_1 = 10 bar = 1.0 x 10^6 Pa	p_1 = 10 bar = 1.0 x 10^6 Pa	p_1 = 10 bar = 1.0 x 10^6 Pa
Valve outlet absolute pressure	p_2 = 7.2 bar = 7.2 x 10^5 Pa	p_2 = 6.9 bar = 6.9 x 10^5 Pa	p_2 = 4.8 bar = 4.8 x 10^5 Pa	p_2 = 4.2 bar = 4.2 x 10^5 Pa	p_2 = 0.5 bar = 5 x 10^4 Pa	p_2 = 0.5 bar = 5 x 10^4 Pa
Inlet density	ρ_1 = 5.3 kg/m³	ρ_1 = 5.3 kg/m³	ρ_1 = 5.3 kg/m³	ρ_1 = 5.3 kg/m³	ρ_1 = 5.3 kg/m³	ρ_1 = 5.3 kg/m³
Inlet absolute temperature	T_1 = 177 °C = 450 K	T_1 = 177 °C = 450 K	T_1 = 177 °C = 450 K	T_1 = 177 °C = 450 K	T_1 = 177 °C = 450 K	T_1 = 177 °C = 450 K
Specific heat ratio	γ = 1.22	γ = 1.22	γ = 1.22	γ = 1.22	γ = 1.22	γ = 1.22
Molecular mass	M = 19.8 kg/kmol	M = 19.8 kg/kmol	M = 19.8 kg/kmol	M = 19.8 kg/kmol	M = 19.8 kg/kmol	M = 19.8 kg/kmol
Required C_v	C_v = 90	C_v = 90	C_v = 90	C_v = 40	C_v = 40	C_v = 30
Valve size	DN 100	DN 100	DN 100	DN 200	DN 200	DN 100
Valve outlet diameter	D = 0.1 m	D = 0.1 m	D = 0.1 m	D = 0.2031 m	D = 0.2031 m	D = 0.1 m
Internal pipe diameter	D_i = 0.2031 m	D_i = 0.2031 m	D_i = 0.2031 m	D_i = 0.2031 m	D_i = 0.2031 m	D_i = 0.15 m
(1) Differential pressure ratio $x = \frac{p_1 - p_2}{p_1}$	x = 0.28	x = 0.31	x = 0.52	x = 0.58	x = 0.95	x = 0.95
(2) Absolute vena contracta pressure at subsonic flow conditions $p_{vc} = p_1 \cdot \left(1 - \frac{x}{(F_{LP}/F_P)^2}\right)$	p_{vc} = 567787 Pa	p_{vc} = 521478 Pa	p_{vc} = 197319 Pa	p_{vc} = 104702 Pa	p_{vc} = -466437 Pa	p_{vc} = -466437 Pa
(3) Vena contracta differential pressure ratio at critical flow conditions $x_{vcc} = 1 - \left(\frac{2}{\gamma + 1}\right)^{\gamma/(\gamma-1)}$	x_{vcc} = 0.439	x_{vcc} = 0.439	x_{vcc} = 0.439	x_{vcc} = 0.439	x_{vcc} = 0.439	x_{vcc} = 0.439
	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
(4) Differential pressure ratio at critical flow conditions $x_C = (F_{LP}/F_P)^2 x_{vcc}$	x_C = 0.285	x_C = 0.285	x_C = 0.285	x_C = 0.285	x_C = 0.285	x_C = 0.285
(5) Recovery correction factor $\alpha \equiv \frac{1 - x_{vcc}}{1 - x_C}$	α = 0.784	α = 0.784	α = 0.784	α = 0.784	α = 0.784	α = 0.784
(6) Differential pressure ratio at break point $x_B = 1 - \frac{1}{\alpha}\left(\frac{1}{\gamma}\right)^{\gamma/(\gamma-1)}$	x_B = 0.576	x_B = 0.576	x_B = 0.576	x_B = 0.576	x_B = 0.576	x_B = 0.576
(7) Differential pressure ratio where region of constant acoustical efficiency begins $x_{CE} = 1 - \frac{1}{22\,\alpha}$	x_{CE} = 0.942	x_{CE} = 0.942	x_{CE} = 0.942	x_{CE} = 0.942	x_{CE} = 0.942	x_{CE} = 0.942

	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
Regime definition Regime I If $x \le x_C$ Regime II If $x_C < x \le x_{vcc}$ Regime III If $x_{vcc} < x \le x_B$ Regime IV If $x_B < x \le x_{CE}$ Regime V If $x_{CE} < x$	$x \le x_C$ $\Rightarrow$ Regime I	$x_C < x \le x_{VCC}$ $\Rightarrow$ Regime II	$x_{VCC} < x \le x_B$ $\Rightarrow$ Regime III	$x_B < x \le x_{CE}$ $\Rightarrow$ Regime IV	$x_{CE} < x$ $\Rightarrow$ Regime V	$x_{CE} < x$ $\Rightarrow$ Regime V
(8b) Hydraulic diameter of a single flow passage $d_H = \frac{4\ A}{l_w}$	d_H = 0.030 m	d_H = 0.030 m	d_H = 0.030 m	d_H = 0.030 m	d_H = 0.030 m	d_H = 0.030 m
(8c) Diameter of a circular orifice $d_o = \sqrt{\frac{4\ N_o\ A}{\pi}}$	d_0 = 0.010 m	d_0 = 0.010 m	d_0 = 0.010 m	d_0 = 0.010 m	d_0 = 0.010 m	d_0 = 0.010 m
(8a) Valve style modifier $F_d = \frac{d_H}{d_o}$	F_d = 0.30	F_d = 0.30	F_d = 0.30	F_d = 0.30	F_d = 0.30	F_d = 0.30
(9) Jet diameter $D_j = N_{14}\ F_d\ \sqrt{C\,(F_{LP}/F_P)}$	$N_{14} = 4.6 \times 10^{-3}$ $\Rightarrow$ D_j = 0.012 m	$N_{14} = 4.6 \times 10^{-3}$ $\Rightarrow$ D_j = 0.012 m	$N_{14} = 4.6 \times 10^{-3}$ $\Rightarrow$ D_j = 0.012 m	$N_{14} = 4.6 \times 10^{-3}$ $\Rightarrow$ D_j = 0.008 m	$N_{14} = 4.6 \times 10^{-3}$ $\Rightarrow$ D_j = 0.008 m	$N_{14} = 4.6 \times 10^{-3}$ $\Rightarrow$ D_j = 0.007 m
Calculations for Regime I						
(Table 3) Stream power of mass flow $W_m = \frac{\dot{m}(M_{vc}c_{vc})^2}{2}$	W_m = 225385 W					
(Table 3) Vena contracta absolute temperature $T_{vc} = T_1\left(1-\frac{x}{(F_{LP}/F_P)^2}\right)^{(\gamma-1)/\gamma}$	T_{vc} = 406 K					
(Table 3) Speed of sound in the vena contracta $c_{vc} = \sqrt{\gamma\frac{p_1}{\rho_1}\left(1-\frac{x}{(F_{LP}/F_P)^2}\right)^{(\gamma-1)/\gamma}}$	c_{vc} = 455.9 m/s					
(Table 3) Mach number at vena contracta $M_{vc} = \sqrt{\left(\frac{2}{\gamma-1}\right)\left[\left(1-\frac{x}{F_L^2}\right)^{(1-\gamma)/\gamma}-1\right]}$	M_{vc} = 0.988					
(Table 3) Acoustical efficiency factor $\eta = \left(1\times10^{A_\eta}\right)(F_{LP}/F_P)^2\cdot M_{vc}^{\ 3}$	A_η = -3.8 $\Rightarrow$ $\eta_1 = 9.9 \times 10^{-5}$					
(11) Sound power $W_a = \eta\ W_m$	W_a = 22.3 W					
(Table 3) Peak frequency $f_p = \frac{Stp\cdot M_{vc}\cdot c_{vc}}{D_j}$	St_p = 0.2 $\Rightarrow$ f_p = 7778 Hz					
Calculations for Regime II						
(Table 3) Speed of sound in the vena contracta $c_{vcc} = \sqrt{\frac{2\gamma}{\gamma+1}\frac{p_1}{\rho_1}}$		c_{vcc} = 455.4 m/s				
(Table 3) Stream power of mass flow $W_m = \frac{\dot{m}(c_{vcc})^2}{2}$		W_{ms} = 237447 W				
(Table 3) Freely expanded jet Mach number $M_j = \text{Minimum of}\begin{bmatrix}\sqrt{\frac{2}{\gamma-1}\left[\left(\frac{1}{\alpha\,(1-x)}\right)^{(\gamma-1)/\gamma}-1\right]}\\ \sqrt{\frac{2}{\gamma-1}\left[(22)^{(\gamma-1)/\gamma}-1\right]}\end{bmatrix}$		M_j = Min(1.03; 2.6) = 1.03				
(Table 3) Acoustical efficiency factor $\eta = \left(1\times10^{A_\eta}\right)\cdot\frac{x}{x_{vcc}}M_j^{\ 6,6(F_{LP}/F_P)^2}$		A_η = -3.8 $\Rightarrow$ $\eta_2 = 1.3 \times 10^{-4}$				
(11) Sound power $W_a = \eta\ W_m$		W_a = 30.4 W				

	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
(Table 3) Peak frequency $f_p = \frac{Stp \cdot M_j \cdot c_{vcc}}{D_j}$		$St_p = 0.2$ ⇒ $f_p = 8115$ Hz				
Calculations for Regime III						
(Table 3) Speed of sound in the vena contracta $c_{vcc} = \sqrt{\frac{2\gamma}{\gamma+1}\frac{p_1}{\rho_1}}$			$c_{vcc} =$ 455.4 m/s			
(Table 3) Stream power of mass flow $W_m = \frac{\dot{m}(c_{vcc})^2}{2}$			$W_{ms} =$ 268553 W			
(Table 3) Freely expanded jet Mach number $M_j = \text{Minimum of} \begin{bmatrix} \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{1}{\alpha(1-x)}\right)^{(\gamma-1)/\gamma}-1\right]} \\ \sqrt{\frac{2}{\gamma-1}\left[(22)^{(\gamma-1)/\gamma}-1\right]} \end{bmatrix}$			$M_j =$ Min(1.32; 2.6) = 1.32			
(Table 3) Acoustical efficiency factor $\eta = \left(1 \times 10^{A_\eta}\right) \cdot M_j^{6,6(F_{LP}/F_P)^2}$			$A_\eta = -3.8$ ⇒ $\eta_3 = 5.3 \times 10^{-4}$			
(11) Sound power $W_a = \eta\, W_m$			$W_a = 141.3$ W			
(Table 3) Peak frequency $f_p = \frac{Stp \cdot M_j \cdot c_{vcc}}{D_j}$			$St_p = 0.2$ ⇒ $f_p = 10407$ Hz			
Calculations for Regime IV						
(Table 3) Speed of sound in the vena contracta $c_{vcc} = \sqrt{\frac{2\gamma}{\gamma+1}\frac{p_1}{\rho_1}}$				$c_{vcc} =$ 455.4 m/s		
(Table 3) Stream power of mass flow $W_m = \frac{\dot{m}(c_{vcc})^2}{2}$				$W_{ms} =$ 122353 W		
(Table 3) Freely expanded jet Mach number $M_j = \text{Minimum of} \begin{bmatrix} \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{1}{\alpha(1-x)}\right)^{(\gamma-1)/\gamma}-1\right]} \\ \sqrt{\frac{2}{\gamma-1}\left[(22)^{(\gamma-1)/\gamma}-1\right]} \end{bmatrix}$				$M_j =$ Min(1.42; 2.6) = 1.42		
(Table 3) Acoustical efficiency factor $\eta = \left(1 \times 10^{A_\eta}\right)\left(\frac{M_j^2}{2}\right)\left(\sqrt{2}\right)^{6,6(F_{LP}/F_P)^2}$				$A_\eta = -3.8$ ⇒ $\eta_4 = 7.0 \times 10^{-4}$		
(11) Sound power $W_a = \eta\, W_m$				$W_a = 86.1$ W		
(Table 3) Peak frequency $f_p = \frac{1.4 \cdot St_p \cdot c_{vcc}}{D_j\sqrt{M_j^2 - 1}}$				$St_p = 0.2$ ⇒ $f_p = 16368$ Hz		
Calculations for Regime V						
(Table 3) Speed of sound in the vena contracta $c_{vcc} = \sqrt{\frac{2\gamma}{\gamma+1}\frac{p_1}{\rho_1}}$					$c_{vcc} =$ 455.4 m/s	$c_{vcc} =$ 455.4 m/s
(Table 3) Stream power of mass flow $W_m = \frac{\dot{m}(c_{vcc})^2}{2}$					$W_{ms} =$ 123389 W	$W_{ms} =$ 92283 W
(Table 3) Freely expanded jet Mach number					$M_j =$ Min(2.7; 2.6) = 2.6	$M_j =$ Min(2.7; 2.6) = 2.6

	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
$\mathrm{M}_j = \text{Minimum of} \begin{bmatrix} \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{1}{\alpha\,(1\text{-}\mathrm{x})}\right)^{(\gamma-1)/\gamma}-1\right]} \\ \sqrt{\frac{2}{\gamma-1}\left[(22)^{(\gamma-1)/\gamma}-1\right]} \end{bmatrix}$						
(Table 3) Acoustical efficiency factor $\eta = \left(1\times 10^{A_\eta}\right)\left(\frac{\mathrm{M}_j^{\ 2}}{2}\right)\left(\sqrt{2}\right)^{6,6(F_{LP}/F_P)^2}$					A_η = -3.8 ⇒ $\eta_5 = 2.4 \times 10^{-3}$	A_η = -3.8 ⇒ $\eta_5 = 2.4 \times 10^{-3}$
(11) Sound power $\mathrm{W}_a = \eta\,\mathrm{W}_m$					W_a = 291.9 W	W_a = 218.3 W
(Table 3) Peak frequency $f_p = \frac{1.4 \cdot St_p \cdot c_{vcc}}{D_j\sqrt{M_j^{\ 2}-1}}$					St_p = 0.2 ⇒ f_p = 6864 Hz	St_p = 0.2 ⇒ f_p = 7926 Hz
Noise calculations						
(13) Outlet density $\rho_2 = \rho_1\left(\frac{p_2}{p_1}\right)$	ρ_2 = 3.8 kg/m³	ρ_2 = 3.7 kg/m³	ρ_2 = 2.5 kg/m³	ρ_2 = 2.2 kg/m³	ρ_2 = 0.3 kg/m³	ρ_2 = 0.3 kg/m³
(14) Speed of sound at downstream conditions $c_2 = \sqrt{\frac{\gamma R T_2}{M}}$	R = 8314 J/kmol x K ⇒ c_2 = 480 m/s	R = 8314 J/kmol x K ⇒ c_2 = 480 m/s	R = 8314 J/kmol x K ⇒ c_2 = 480 m/s	R = 8314 J/kmol x K ⇒ c_2 = 480 m/s	R = 8314 J/kmol x K ⇒ c_2 = 480 m/s	R = 8314 J/kmol x K ⇒ c_2 = 480 m/s
(15) Mach number at valve outlet $M_\mathrm{o} = \frac{4\,\dot m}{\pi D^2 \rho_2 c_2}$	M_o = 0.15 <0.3 ⇒ calculations are appropriate	M_o = 0.17 <0.3 ⇒ calculations are appropriate	M_o = 0.27 <0.3 ⇒ calculations are appropriate	M_o = 0.03 <0.3 ⇒ calculations are appropriate	M_o = 0.29 <0.3 ⇒ calculations are appropriate	M_o = 0.89 >0.3 ⇒ calculation of eqs. (54)-(63) is necessary
(17) Mach number in downstream pipe $M_2 = \frac{4\,\dot m}{\pi\,\mathrm{D_i}^2 \rho_2 c_2} < 0.3$	M_2 = 0.04 <0.3 ⇒ M_2 = 0.04	M_2 = 0.04 <0.3 ⇒ M_2 = 0.04	M_2 = 0.07 <0.3 ⇒ M_2 = 0.07	M_2 = 0.03 <0.3 ⇒ M_2 = 0.03	M_2 = 0.29 <0.3 ⇒ M_2 = 0.29	M_2 = 0.4 > 0.3 ⇒ M_2 = 0.3
(16) Correction for Mach number $L_\mathrm{g} = 16\log_{10}\left(\frac{1}{1-M_2}\right)$	L_G = 0.26 dB	L_G = 0.29 dB	L_G = 0.47 dB	L_G = 0.24 dB	L_G = 2.4 dB	L_G = 2.5 dB
(18) Overall internal sound-pressure level $\mathrm{L}_{pi} = 10\,log_{10}\left[\frac{\left(3{,}2\times 10^9\right)\mathrm{W}_a\,\rho_2\,\mathrm{c}_2}{\mathrm{D}_i^{\ 2}}\right] + L_g$	L_{pi} = 155.3 dB	L_{pi} = 156.5 dB	L_{pi} = 161.7 dB	L_{pi} = 158.8 dB	L_{pi} = 157 dB	L_{pi} = 158.4 dB
(19) Frequency dependent internal sound-pressure level (third octave bands: 12.5 Hz – 20 000 Hz) $\mathrm{L}_{pi}(f_i) = \mathrm{L}_{pi} - 8 - 10\cdot\log\left\{\left[1+\left(\frac{f_i}{2\cdot f_p}\right)^{2.5}\right]\cdot\left[1+\left(\frac{f_p}{2\cdot f_i}\right)^{1.7}\right]\right\}$	$L_{pi,1}$ = 105 dB $L_{pi,2}$ = 107 dB $L_{pi,3}$ = 108 dB $L_{pi,4}$ = 110 dB $L_{pi,5}$ = 112 dB $L_{pi,6}$ = 113 dB $L_{pi,7}$ = 115 dB $L_{pi,8}$ = 117 dB $L_{pi,9}$ = 119 dB $L_{pi,10}$ = 120 dB $L_{pi,11}$ = 122 dB $L_{pi,12}$ = 124 dB $L_{pi,13}$ = 125 dB $L_{pi,14}$ = 127 dB $L_{pi,15}$ = 129 dB $L_{pi,16}$ = 130 dB $L_{pi,17}$ = 132 dB $L_{pi,18}$ = 134 dB $L_{pi,19}$ = 135 dB $L_{pi,20}$ = 137 dB $L_{pi,21}$ = 138 dB $L_{pi,22}$ = 140 dB $L_{pi,23}$ = 141 dB $L_{pi,24}$ = 142 dB $L_{pi,25}$ = 143 dB $L_{pi,26}$ = 144 dB $L_{pi,27}$ = 145 dB $L_{pi,28}$ = 145 dB $L_{pi,29}$ = 145 dB $L_{pi,30}$ = 145 dB $L_{pi,31}$ = 145 dB $L_{pi,32}$ = 144 dB $L_{pi,33}$ = 142 dB	$L_{pi,1}$ = 106 dB $L_{pi,2}$ = 108 dB $L_{pi,3}$ = 109 dB $L_{pi,4}$ = 111 dB $L_{pi,5}$ = 113 dB $L_{pi,6}$ = 114 dB $L_{pi,7}$ = 116 dB $L_{pi,8}$ = 118 dB $L_{pi,9}$ = 119 dB $L_{pi,10}$ = 121 dB $L_{pi,11}$ = 123 dB $L_{pi,12}$ = 125 dB $L_{pi,13}$ = 126 dB $L_{pi,14}$ = 128 dB $L_{pi,15}$ = 130 dB $L_{pi,16}$ = 131 dB $L_{pi,17}$ = 133 dB $L_{pi,18}$ = 135 dB $L_{pi,19}$ = 136 dB $L_{pi,20}$ = 138 dB $L_{pi,21}$ = 139 dB $L_{pi,22}$ = 141 dB $L_{pi,23}$ = 142 dB $L_{pi,24}$ = 143 dB $L_{pi,25}$ = 144 dB $L_{pi,26}$ = 145 dB $L_{pi,27}$ = 146 dB $L_{pi,28}$ = 146 dB $L_{pi,29}$ = 147 dB $L_{pi,30}$ = 146 dB $L_{pi,31}$ = 146 dB $L_{pi,32}$ = 145 dB $L_{pi,33}$ = 144 dB	$L_{pi,1}$ = 109 dB $L_{pi,2}$ = 111 dB $L_{pi,3}$ = 113 dB $L_{pi,4}$ = 114 dB $L_{pi,5}$ = 116 dB $L_{pi,6}$ = 118 dB $L_{pi,7}$ = 119 dB $L_{pi,8}$ = 121 dB $L_{pi,9}$ = 123 dB $L_{pi,10}$ = 125 dB $L_{pi,11}$ = 126 dB $L_{pi,12}$ = 128 dB $L_{pi,13}$ = 130 dB $L_{pi,14}$ = 131 dB $L_{pi,15}$ = 133 dB $L_{pi,16}$ = 135 dB $L_{pi,17}$ = 136 dB $L_{pi,18}$ = 138 dB $L_{pi,19}$ = 140 dB $L_{pi,20}$ = 141 dB $L_{pi,21}$ = 143 dB $L_{pi,22}$ = 144 dB $L_{pi,23}$ = 146 dB $L_{pi,24}$ = 147 dB $L_{pi,25}$ = 148 dB $L_{pi,26}$ = 150 dB $L_{pi,27}$ = 150 dB $L_{pi,28}$ = 151 dB $L_{pi,29}$ = 152 dB $L_{pi,30}$ = 152 dB $L_{pi,31}$ = 152 dB $L_{pi,32}$ = 151 dB $L_{pi,33}$ = 151 dB	$L_{pi,1}$ = 103 dB $L_{pi,2}$ = 105 dB $L_{pi,3}$ = 106 dB $L_{pi,4}$ = 108 dB $L_{pi,5}$ = 110 dB $L_{pi,6}$ = 111 dB $L_{pi,7}$ = 113 dB $L_{pi,8}$ = 115 dB $L_{pi,9}$ = 117 dB $L_{pi,10}$ = 118 dB $L_{pi,11}$ = 120 dB $L_{pi,12}$ = 122 dB $L_{pi,13}$ = 123 dB $L_{pi,14}$ = 125 dB $L_{pi,15}$ = 127 dB $L_{pi,16}$ = 128 dB $L_{pi,17}$ = 130 dB $L_{pi,18}$ = 132 dB $L_{pi,19}$ = 134 dB $L_{pi,20}$ = 135 dB $L_{pi,21}$ = 137 dB $L_{pi,22}$ = 138 dB $L_{pi,23}$ = 140 dB $L_{pi,24}$ = 141 dB $L_{pi,25}$ = 143 dB $L_{pi,26}$ = 144 dB $L_{pi,27}$ = 146 dB $L_{pi,28}$ = 147 dB $L_{pi,29}$ = 148 dB $L_{pi,30}$ = 148 dB $L_{pi,31}$ = 149 dB $L_{pi,32}$ = 149 dB $L_{pi,33}$ = 149 dB	$L_{pi,1}$ = 108 dB $L_{pi,2}$ = 109 dB $L_{pi,3}$ = 111 dB $L_{pi,4}$ = 113 dB $L_{pi,5}$ = 114 dB $L_{pi,6}$ = 116 dB $L_{pi,7}$ = 118 dB $L_{pi,8}$ = 119 dB $L_{pi,9}$ = 121 dB $L_{pi,10}$ = 123 dB $L_{pi,11}$ = 124 dB $L_{pi,12}$ = 126 dB $L_{pi,13}$ = 128 dB $L_{pi,14}$ = 130 dB $L_{pi,15}$ = 131 dB $L_{pi,16}$ = 133 dB $L_{pi,17}$ = 135 dB $L_{pi,18}$ = 136 dB $L_{pi,19}$ = 138 dB $L_{pi,20}$ = 139 dB $L_{pi,21}$ = 141 dB $L_{pi,22}$ = 142 dB $L_{pi,23}$ = 143 dB $L_{pi,24}$ = 145 dB $L_{pi,25}$ = 146 dB $L_{pi,26}$ = 146 dB $L_{pi,27}$ = 147 dB $L_{pi,28}$ = 147 dB $L_{pi,29}$ = 147 dB $L_{pi,30}$ = 147 dB $L_{pi,31}$ = 146 dB $L_{pi,32}$ = 145 dB $L_{pi,33}$ = 143 dB	$L_{pi,1}$ = 108 dB $L_{pi,2}$ = 110 dB $L_{pi,3}$ = 111 dB $L_{pi,4}$ = 113 dB $L_{pi,5}$ = 115 dB $L_{pi,6}$ = 117 dB $L_{pi,7}$ = 118 dB $L_{pi,8}$ = 120 dB $L_{pi,9}$ = 122 dB $L_{pi,10}$ = 123 dB $L_{pi,11}$ = 125 dB $L_{pi,12}$ = 127 dB $L_{pi,13}$ = 128 dB $L_{pi,14}$ = 130 dB $L_{pi,15}$ = 132 dB $L_{pi,16}$ = 133dB $L_{pi,17}$ = 135 dB $L_{pi,18}$ = 137 dB $L_{pi,19}$ = 138 dB $L_{pi,20}$ = 140 dB $L_{pi,21}$ = 141 dB $L_{pi,22}$ = 143 dB $L_{pi,23}$ = 144 dB $L_{pi,24}$ = 145 dB $L_{pi,25}$ = 146 dB $L_{pi,26}$ = 147 dB $L_{pi,27}$ = 148 dB $L_{pi,28}$ = 148 dB $L_{pi,29}$ = 149 dB $L_{pi,30}$ = 148 dB $L_{pi,31}$ = 148 dB $L_{pi,32}$ = 147 dB $L_{pi,33}$ = 146 dB
Note	M_0 <0.3 ⇒ calculation of eqs. (34)-(43) is not necessary	M_0 <0.3 ⇒ calculation of eqs. (34)-(43) is not necessary	M_0 <0.3 ⇒ calculation of eqs. (34)-(43) is not necessary	M_0 <0.3 ⇒ calculation of eqs. (34)-(43) is not necessary	M_0 <0.3 ⇒ calculation of eqs. (34)-(43) is not necessary	M_0 >0.3 ⇒ calculation of eqs. (34)-(43) is necessary
(34) Gas velocity in downstream pipe $\mathrm{U}_p = \frac{4\,\dot{\mathrm{m}}}{\pi\,\rho_2\,\mathrm{D}_i^{\ 2}} \le 0.8\cdot c_2$						U_p = 190 m/s

	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
(35) Gas velocity in the inlet of diameter expander $U_R = \frac{U_p \, D_i^2}{\beta \, d_i^2} \le c_2$						d_i = D and β = 0.93 (assumed) $\Rightarrow$ U_R = 460m/s
(36) Converted stream power in the expander $W_{mR} = \frac{\dot{m} \, U_R^2}{2} \left[\left(1 - \frac{d_i^2}{D_i^2} \right)^2 + 0{,}2 \right]$						W_{mR} = 47854 W
(37) Peak frequency in valve outlet or reduced diameter of expander $f_{pR} = \frac{St_p \, U_R}{d_i}$						f_{pR} = 920 Hz
(39) Mach number in the entrance to expander $M_R = \frac{U_R}{c_2}$						M_R = 0.96
(38) Acoustical efficiency factor for noise created by outlet flow in expander $\eta_R = \left(1 \times 10^{A_\eta}\right) M_R^3$						$\eta_R = 8.8 \times 10^{-4}$
(40) Sound power for noise generated by the outlet flow and propagating downstream $W_{aR} = \eta_R \, W_{mR}$						W_{aR} = 42.0 W
(41) Overall internal sound-pressure level at pipe wall for noise created by outlet flow in expander $L_{piR} = 10 \, log_{10} \left[\frac{\left(3{,}2 \times 10^9\right) W_{aR} \, \rho_2 c_2}{D_i^2} \right] + L_g$						L_{piR} = 151 dB
(42) Frequency dependent internal sound-pressure level at pipe wall for noise created by outlet flow in expander (third octave bands: 12,5 Hz – 20 000 Hz) $L_{piR}(f_i) = L_{piR} - 8 - 10 \cdot \log \left\{ \left[1 + \left(\frac{f_i}{2 \cdot f_{pR}} \right)^{2.5} \right] \cdot \left[1 + \left(\frac{f_{pR}}{2 \cdot f_i} \right)^{1.7} \right] \right\}$						$L_{piR,1}$ = 117 dB $L_{piR,2}$ = 118 dB $L_{piR,3}$ = 120 dB $L_{piR,4}$ = 122 dB $L_{piR,5}$ = 123 dB $L_{piR,6}$ = 125 dB $L_{piR,7}$ = 127 dB $L_{piR,8}$ = 128 dB $L_{piR,9}$ = 130 dB $L_{piR,10}$ = 132 dB $L_{piR,11}$ = 133 dB $L_{piR,12}$ = 135 dB $L_{piR,13}$ = 136 dB $L_{piR,14}$ = 137 dB $L_{piR,15}$ = 139 dB $L_{piR,16}$ = 140 dB $L_{piR,17}$ = 140 dB $L_{piR,18}$ = 141 dB $L_{piR,19}$ = 141 dB $L_{piR,20}$ = 141 dB $L_{piR,21}$ = 141 dB $L_{piR,22}$ = 140 dB $L_{piR,23}$ = 139 dB $L_{piR,24}$ = 138 dB $L_{piR,25}$ = 136 dB $L_{piR,26}$ = 134 dB $L_{piR,27}$ = 132 dB $L_{piR,28}$ = 130 dB $L_{piR,29}$ = 127 dB $L_{piR,30}$ = 125 dB $L_{piR,31}$ = 122 dB $L_{piR,32}$ = 120 dB $L_{piR,33}$ = 117 dB

	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
(43) Combined internal sound-pressure level at pipe wall, caused by valve trim and expander (third octave bands: 12,5 Hz – 20 000 Hz) $L_{piS}(f_i) = 10\,log_{10}\left(10^{L_{pi}(f_i)/10} + 10^{L_{piR}(f_i)/10}\right)$						$L_{piS,1}$ = 117 dB $L_{piS,2}$ = 119 dB $L_{piS,3}$ = 121 dB $L_{piS,4}$ = 122 dB $L_{piS,5}$ = 124 dB $L_{piS,6}$ = 126 dB $L_{piS,7}$ = 127 dB $L_{piS,8}$ = 129 dB $L_{piS,9}$ = 131 dB $L_{piS,10}$ = 132 dB $L_{piS,11}$ = 134 dB $L_{piS,12}$ = 135 dB $L_{piS,13}$ = 137 dB $L_{piS,14}$ = 138 dB $L_{piS,15}$ = 139 dB $L_{piS,16}$ = 141 dB $L_{piS,17}$ = 142 dB $L_{piS,18}$ = 142 dB $L_{piS,19}$ = 143 dB $L_{piS,20}$ = 144 dB $L_{piS,21}$ = 144 dB $L_{piS,22}$ = 145 dB $L_{piS,23}$ = 145 dB $L_{piS,24}$ = 146 dB $L_{piS,25}$ = 147 dB $L_{piS,26}$ = 148 dB $L_{piS,27}$ = 148 dB $L_{piS,28}$ = 148 dB $L_{piS,29}$ = 149 dB $L_{piS,30}$ = 148 dB $L_{piS,31}$ = 148 dB $L_{piS,32}$ = 147 dB $L_{piS,33}$ = 146 dB
(21) Ring frequency $f_r = \frac{c_s}{\pi D_i}$	c_S = 5000 m/s ⇒ f_r = 7836 Hz	c_S = 5000 m/s ⇒ f_r = 7836 Hz	c_S = 5000 m/s ⇒ f_r = 7836 Hz	c_S = 5000 m/s ⇒ f_r = 7836 Hz	c_S = 5000 m/s ⇒ f_r = 7836 Hz	c_S = 5000 m/s ⇒ f_r = 10610 Hz
(22) Internal coincidence pipe frequency $f_o = \frac{f_r}{4}\left(\frac{c_2}{c_a}\right)$	c_a = 343 m/s ⇒ f_0 = 2742 Hz	c_a = 343 m/s ⇒ f_0 = 2742 Hz	c_a = 343 m/s ⇒ f_0 = 2742 Hz	c_a = 343 m/s ⇒ f_0 = 2742 Hz	c_a = 343 m/s ⇒ f_0 = 2742 Hz	c_a = 343 m/s ⇒ f_0 = 3713 Hz
(23) External coincidence frequency $f_g = \frac{\sqrt{3}\,(c_a)^2}{\pi\, t_S (c_s)}$	f_g = 1622 Hz	f_g = 1622 Hz	f_g = 1622 Hz	f_g = 1622 Hz	f_g = 1622 Hz	f_g = 1622 Hz

	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
(Table 6) Frequency factor G_x (third octave bands: 12,5 Hz – 20 000 Hz) $G_x(f_i)=\begin{cases}\left(\frac{f_o}{f_r}\right)^{2/3}\left(\frac{f_i}{f_o}\right)^4 & for\ f_i < f_0\\ \left(\frac{f_i}{f_r}\right)^{1/2} & for\ f_i \geq f_0\ and\ f_i < f_r\\ 1 & for\ f_i \geq f_0\ and\ f_i \geq f_r\end{cases}$	$G_{x,1} = 2.1 \times 10^{-10}$ $G_{x,2} = 5.8 \times 10^{-10}$ $G_{x,3} = 1.4 \times 10^{-9}$ $G_{x,4} = 3.4 \times 10^{-9}$ $G_{x,5} = 8.6 \times 10^{-9}$ $G_{x,6} = 2.2 \times 10^{-8}$ $G_{x,7} = 5.5 \times 10^{-8}$ $G_{x,8} = 1.4 \times 10^{-7}$ $G_{x,9} = 3.6 \times 10^{-7}$ $G_{x,10} = 8.8 \times 10^{-7}$ $G_{x,11} = 2.1 \times 10^{-6}$ $G_{x,12} = 5.8 \times 10^{-6}$ $G_{x,13} = 1.4 \times 10^{-5}$ $G_{x,14} = 3.4 \times 10^{-5}$ $G_{x,15} = 8.6 \times 10^{-5}$ $G_{x,16} = 2.2 \times 10^{-4}$ $G_{x,17} = 5.5 \times 10^{-4}$ $G_{x,18} = 0.0014$ $G_{x,19} = 0.0036$ $G_{x,20} = 0.0088$ $G_{x,21} = 0.021$ $G_{x,22} = 0.058$ $G_{x,23} = 0.14$ $G_{x,24} = 0.34$ $G_{x,25} = 0.63$ $G_{x,26} = 0.71$ $G_{x,27} = 0.8$ $G_{x,28} = 0.9$ $G_{x,29} = 1$ $G_{x,30} = 1$ $G_{x,31} = 1$ $G_{x,32} = 1$ $G_{x,33} = 1$	$G_{x,1} = 2.1 \times 10^{-10}$ $G_{x,2} = 5.8 \times 10^{-10}$ $G_{x,3} = 1.4 \times 10^{-9}$ $G_{x,4} = 3.4 \times 10^{-9}$ $G_{x,5} = 8.6 \times 10^{-9}$ $G_{x,6} = 2.2 \times 10^{-8}$ $G_{x,7} = 5.5 \times 10^{-8}$ $G_{x,8} = 1.4 \times 10^{-7}$ $G_{x,9} = 3.6 \times 10^{-7}$ $G_{x,10} = 8.8 \times 10^{-7}$ $G_{x,11} = 2.1 \times 10^{-6}$ $G_{x,12} = 5.8 \times 10^{-6}$ $G_{x,13} = 1.4 \times 10^{-5}$ $G_{x,14} = 3.4 \times 10^{-5}$ $G_{x,15} = 8.6 \times 10^{-5}$ $G_{x,16} = 2.2 \times 10^{-4}$ $G_{x,17} = 5.5 \times 10^{-4}$ $G_{x,18} = 0.0014$ $G_{x,19} = 0.0036$ $G_{x,20} = 0.0088$ $G_{x,21} = 0.021$ $G_{x,22} = 0.058$ $G_{x,23} = 0.14$ $G_{x,24} = 0.34$ $G_{x,25} = 0.63$ $G_{x,26} = 0.71$ $G_{x,27} = 0.8$ $G_{x,28} = 0.9$ $G_{x,29} = 1$ $G_{x,30} = 1$ $G_{x,31} = 1$ $G_{x,32} = 1$ $G_{x,33} = 1$	$G_{x,1} = 2.1 \times 10^{-10}$ $G_{x,2} = 5.8 \times 10^{-10}$ $G_{x,3} = 1.4 \times 10^{-9}$ $G_{x,4} = 3.4 \times 10^{-9}$ $G_{x,5} = 8.6 \times 10^{-9}$ $G_{x,6} = 2.2 \times 10^{-8}$ $G_{x,7} = 5.5 \times 10^{-8}$ $G_{x,8} = 1.4 \times 10^{-7}$ $G_{x,9} = 3.6 \times 10^{-7}$ $G_{x,10} = 8.8 \times 10^{-7}$ $G_{x,11} = 2.1 \times 10^{-6}$ $G_{x,12} = 5.8 \times 10^{-6}$ $G_{x,13} = 1.4 \times 10^{-5}$ $G_{x,14} = 3.4 \times 10^{-5}$ $G_{x,15} = 8.6 \times 10^{-5}$ $G_{x,16} = 2.2 \times 10^{-4}$ $G_{x,17} = 5.5 \times 10^{-4}$ $G_{x,18} = 0.0014$ $G_{x,19} = 0.0036$ $G_{x,20} = 0.0088$ $G_{x,21} = 0.021$ $G_{x,22} = 0.058$ $G_{x,23} = 0.14$ $G_{x,24} = 0.34$ $G_{x,25} = 0.63$ $G_{x,26} = 0.71$ $G_{x,27} = 0.8$ $G_{x,28} = 0.9$ $G_{x,29} = 1$ $G_{x,30} = 1$ $G_{x,31} = 1$ $G_{x,32} = 1$ $G_{x,33} = 1$	$G_{x,1} = 2.1 \times 10^{-10}$ $G_{x,2} = 5.8 \times 10^{-10}$ $G_{x,3} = 1.4 \times 10^{-9}$ $G_{x,4} = 3.4 \times 10^{-9}$ $G_{x,5} = 8.6 \times 10^{-9}$ $G_{x,6} = 2.2 \times 10^{-8}$ $G_{x,7} = 5.5 \times 10^{-8}$ $G_{x,8} = 1.4 \times 10^{-7}$ $G_{x,9} = 3.6 \times 10^{-7}$ $G_{x,10} = 8.8 \times 10^{-7}$ $G_{x,11} = 2.1 \times 10^{-6}$ $G_{x,12} = 5.8 \times 10^{-6}$ $G_{x,13} = 1.4 \times 10^{-5}$ $G_{x,14} = 3.4 \times 10^{-5}$ $G_{x,15} = 8.6 \times 10^{-5}$ $G_{x,16} = 2.2 \times 10^{-4}$ $G_{x,17} = 5.5 \times 10^{-4}$ $G_{x,18} = 0.0014$ $G_{x,19} = 0.0036$ $G_{x,20} = 0.0088$ $G_{x,21} = 0.021$ $G_{x,22} = 0.058$ $G_{x,23} = 0.14$ $G_{x,24} = 0.34$ $G_{x,25} = 0.63$ $G_{x,26} = 0.71$ $G_{x,27} = 0.8$ $G_{x,28} = 0.9$ $G_{x,29} = 1$ $G_{x,30} = 1$ $G_{x,31} = 1$ $G_{x,32} = 1$ $G_{x,33} = 1$	$G_{x,1} = 2.1 \times 10^{-10}$ $G_{x,2} = 5.8 \times 10^{-10}$ $G_{x,3} = 1.4 \times 10^{-9}$ $G_{x,4} = 3.4 \times 10^{-9}$ $G_{x,5} = 8.6 \times 10^{-9}$ $G_{x,6} = 2.2 \times 10^{-8}$ $G_{x,7} = 5.5 \times 10^{-8}$ $G_{x,8} = 1.4 \times 10^{-7}$ $G_{x,9} = 3.6 \times 10^{-7}$ $G_{x,10} = 8.8 \times 10^{-7}$ $G_{x,11} = 2.1 \times 10^{-6}$ $G_{x,12} = 5.8 \times 10^{-6}$ $G_{x,13} = 1.4 \times 10^{-5}$ $G_{x,14} = 3.4 \times 10^{-5}$ $G_{x,15} = 8.6 \times 10^{-5}$ $G_{x,16} = 2.2 \times 10^{-4}$ $G_{x,17} = 5.5 \times 10^{-4}$ $G_{x,18} = 0.0014$ $G_{x,19} = 0.0036$ $G_{x,20} = 0.0088$ $G_{x,21} = 0.021$ $G_{x,22} = 0.058$ $G_{x,23} = 0.14$ $G_{x,24} = 0.34$ $G_{x,25} = 0.63$ $G_{x,26} = 0.71$ $G_{x,27} = 0.8$ $G_{x,28} = 0.9$ $G_{x,29} = 1$ $G_{x,30} = 1$ $G_{x,31} = 1$ $G_{x,32} = 1$ $G_{x,33} = 1$	$G_{x,1} = 6.4 \times 10^{-11}$ $G_{x,2} = 1.7 \times 10^{-10}$ $G_{x,3} = 4.2 \times 10^{-10}$ $G_{x,4} = 1.0 \times 10^{-9}$ $G_{x,5} = 2.6 \times 10^{-9}$ $G_{x,6} = 6.7 \times 10^{-9}$ $G_{x,7} = 1.6 \times 10^{-8}$ $G_{x,8} = 4.1 \times 10^{-8}$ $G_{x,9} = 1.1 \times 10^{-7}$ $G_{x,10} = 2.6 \times 10^{-7}$ $G_{x,11} = 6.4 \times 10^{-7}$ $G_{x,12} = 1.7 \times 10^{-6}$ $G_{x,13} = 4.2 \times 10^{-6}$ $G_{x,14} = 1.0 \times 10^{-5}$ $G_{x,15} = 2.6 \times 10^{-5}$ $G_{x,16} = 6.7 \times 10^{-5}$ $G_{x,17} = 1.6 \times 10^{-4}$ $G_{x,18} = 4.1 \times 10^{-4}$ $G_{x,19} = 0.0011$ $G_{x,20} = 0.0026$ $G_{x,21} = 0.006$ $G_{x,22} = 0.017$ $G_{x,23} = 0.04$ $G_{x,24} = 0.1$ $G_{x,25} = 0.26$ $G_{x,26} = 0.61$ $G_{x,27} = 0.69$ $G_{x,28} = 0.77$ $G_{x,29} = 0.87$ $G_{x,30} = 0.97$ $G_{x,31} = 1$ $G_{x,32} = 1$ $G_{x,33} = 1$
(Table 6) Frequency factor G_y (third octave bands: 12,5 Hz – 20 000 Hz) $G_y(f_i)=\begin{cases}\left(\frac{f_o}{f_g}\right) & for\ f_i < f_0\ and\ f_0 < f_g\\ 1 & for\ f_i < f_0\ and\ f_0 \geq f_g\\ \left(\frac{f_i}{f_g}\right) & for\ f_i \geq f_0\ and\ f_i < f_g\\ 1 & for\ f_i \geq f_0\ and\ f_i \geq f_g\end{cases}$	$G_{y,1} = 1$ $G_{y,2} = 1$ $G_{y,3} = 1$ $G_{y,4} = 1$ $G_{y,5} = 1$ $G_{y,6} = 1$ $G_{y,7} = 1$ $G_{y,8} = 1$ $G_{y,9} = 1$ $G_{y,10} = 1$ $G_{y,11} = 1$ $G_{y,12} = 1$ $G_{y,13} = 1$ $G_{y,14} = 1$ $G_{y,15} = 1$ $G_{y,16} = 1$ $G_{y,17} = 1$ $G_{y,18} = 1$ $G_{y,19} = 1$ $G_{y,20} = 1$ $G_{y,21} = 1$ $G_{y,22} = 1$ $G_{y,23} = 1$ $G_{y,24} = 1$ $G_{y,25} = 1$ $G_{y,26} = 1$ $G_{y,27} = 1$ $G_{y,28} = 1$ $G_{y,29} = 1$ $G_{y,30} = 1$ $G_{y,31} = 1$ $G_{y,32} = 1$ $G_{y,33} = 1$	$G_{y,1} = 1$ $G_{y,2} = 1$ $G_{y,3} = 1$ $G_{y,4} = 1$ $G_{y,5} = 1$ $G_{y,6} = 1$ $G_{y,7} = 1$ $G_{y,8} = 1$ $G_{y,9} = 1$ $G_{y,10} = 1$ $G_{y,11} = 1$ $G_{y,12} = 1$ $G_{y,13} = 1$ $G_{y,14} = 1$ $G_{y,15} = 1$ $G_{y,16} = 1$ $G_{y,17} = 1$ $G_{y,18} = 1$ $G_{y,19} = 1$ $G_{y,20} = 1$ $G_{y,21} = 1$ $G_{y,22} = 1$ $G_{y,23} = 1$ $G_{y,24} = 1$ $G_{y,25} = 1$ $G_{y,26} = 1$ $G_{y,27} = 1$ $G_{y,28} = 1$ $G_{y,29} = 1$ $G_{y,30} = 1$ $G_{y,31} = 1$ $G_{y,32} = 1$ $G_{y,33} = 1$	$G_{y,1} = 1$ $G_{y,2} = 1$ $G_{y,3} = 1$ $G_{y,4} = 1$ $G_{y,5} = 1$ $G_{y,6} = 1$ $G_{y,7} = 1$ $G_{y,8} = 1$ $G_{y,9} = 1$ $G_{y,10} = 1$ $G_{y,11} = 1$ $G_{y,12} = 1$ $G_{y,13} = 1$ $G_{y,14} = 1$ $G_{y,15} = 1$ $G_{y,16} = 1$ $G_{y,17} = 1$ $G_{y,18} = 1$ $G_{y,19} = 1$ $G_{y,20} = 1$ $G_{y,21} = 1$ $G_{y,22} = 1$ $G_{y,23} = 1$ $G_{y,24} = 1$ $G_{y,25} = 1$ $G_{y,26} = 1$ $G_{y,27} = 1$ $G_{y,28} = 1$ $G_{y,29} = 1$ $G_{y,30} = 1$ $G_{y,31} = 1$ $G_{y,32} = 1$ $G_{y,33} = 1$	$G_{y,1} = 1$ $G_{y,2} = 1$ $G_{y,3} = 1$ $G_{y,4} = 1$ $G_{y,5} = 1$ $G_{y,6} = 1$ $G_{y,7} = 1$ $G_{y,8} = 1$ $G_{y,9} = 1$ $G_{y,10} = 1$ $G_{y,11} = 1$ $G_{y,12} = 1$ $G_{y,13} = 1$ $G_{y,14} = 1$ $G_{y,15} = 1$ $G_{y,16} = 1$ $G_{y,17} = 1$ $G_{y,18} = 1$ $G_{y,19} = 1$ $G_{y,20} = 1$ $G_{y,21} = 1$ $G_{y,22} = 1$ $G_{y,23} = 1$ $G_{y,24} = 1$ $G_{y,25} = 1$ $G_{y,26} = 1$ $G_{y,27} = 1$ $G_{y,28} = 1$ $G_{y,29} = 1$ $G_{y,30} = 1$ $G_{y,31} = 1$ $G_{y,32} = 1$ $G_{y,33} = 1$	$G_{y,1} = 1$ $G_{y,2} = 1$ $G_{y,3} = 1$ $G_{y,4} = 1$ $G_{y,5} = 1$ $G_{y,6} = 1$ $G_{y,7} = 1$ $G_{y,8} = 1$ $G_{y,9} = 1$ $G_{y,10} = 1$ $G_{y,11} = 1$ $G_{y,12} = 1$ $G_{y,13} = 1$ $G_{y,14} = 1$ $G_{y,15} = 1$ $G_{y,16} = 1$ $G_{y,17} = 1$ $G_{y,18} = 1$ $G_{y,19} = 1$ $G_{y,20} = 1$ $G_{y,21} = 1$ $G_{y,22} = 1$ $G_{y,23} = 1$ $G_{y,24} = 1$ $G_{y,25} = 1$ $G_{y,26} = 1$ $G_{y,27} = 1$ $G_{y,28} = 1$ $G_{y,29} = 1$ $G_{y,30} = 1$ $G_{y,31} = 1$ $G_{y,32} = 1$ $G_{y,33} = 1$	$G_{y,1} = 1$ $G_{y,2} = 1$ $G_{y,3} = 1$ $G_{y,4} = 1$ $G_{y,5} = 1$ $G_{y,6} = 1$ $G_{y,7} = 1$ $G_{y,8} = 1$ $G_{y,9} = 1$ $G_{y,10} = 1$ $G_{y,11} = 1$ $G_{y,12} = 1$ $G_{y,13} = 1$ $G_{y,14} = 1$ $G_{y,15} = 1$ $G_{y,16} = 1$ $G_{y,17} = 1$ $G_{y,18} = 1$ $G_{y,19} = 1$ $G_{y,20} = 1$ $G_{y,21} = 1$ $G_{y,22} = 1$ $G_{y,23} = 1$ $G_{y,24} = 1$ $G_{y,25} = 1$ $G_{y,26} = 1$ $G_{y,27} = 1$ $G_{y,28} = 1$ $G_{y,29} = 1$ $G_{y,30} = 1$ $G_{y,31} = 1$ $G_{y,32} = 1$ $G_{y,33} = 1$	$G_{y,1} = 1$ $G_{y,2} = 1$ $G_{y,3} = 1$ $G_{y,4} = 1$ $G_{y,5} = 1$ $G_{y,6} = 1$ $G_{y,7} = 1$ $G_{y,8} = 1$ $G_{y,9} = 1$ $G_{y,10} = 1$ $G_{y,11} = 1$ $G_{y,12} = 1$ $G_{y,13} = 1$ $G_{y,14} = 1$ $G_{y,15} = 1$ $G_{y,16} = 1$ $G_{y,17} = 1$ $G_{y,18} = 1$ $G_{y,19} = 1$ $G_{y,20} = 1$ $G_{y,21} = 1$ $G_{y,22} = 1$ $G_{y,23} = 1$ $G_{y,24} = 1$ $G_{y,25} = 1$ $G_{y,26} = 1$ $G_{y,27} = 1$ $G_{y,28} = 1$ $G_{y,29} = 1$ $G_{y,30} = 1$ $G_{y,31} = 1$ $G_{y,32} = 1$ $G_{y,33} = 1$
(20c) Frequency-dependent structural loss factor (third octave bands: 12,5 Hz – 20 000 Hz) $\eta_s(f_i)=\sqrt{\frac{f_s}{100 f_i}}$	$\eta_{S,1} = 0.028$ $\eta_{S,2} = 0.025$ $\eta_{S,3} = 0.022$ $\eta_{S,4} = 0.02$ $\eta_{S,5} = 0.018$ $\eta_{S,6} = 0.016$ $\eta_{S,7} = 0.014$ $\eta_{S,8} = 0.013$ $\eta_{S,9} = 0.011$ $\eta_{S,10} = 0.01$ $\eta_{S,11} = 0.0089$ $\eta_{S,12} = 0.0079$ $\eta_{S,13} = 0.0071$ $\eta_{S,14} = 0.0063$ $\eta_{S,15} = 0.0056$ $\eta_{S,16} = 0.005$ $\eta_{S,17} = 0.0045$ $\eta_{S,18} = 0.004$ $\eta_{S,19} = 0.0035$ $\eta_{S,20} = 0.0032$ $\eta_{S,21} = 0.0028$ $\eta_{S,22} = 0.0025$ $\eta_{S,23} = 0.0022$ $\eta_{S,24} = 0.002$ $\eta_{S,25} = 0.0018$ $\eta_{S,26} = 0.0016$ $\eta_{S,27} = 0.0014$ $\eta_{S,28} = 0.0013$ $\eta_{S,29} = 0.0011$	$\eta_{S,1} = 0.028$ $\eta_{S,2} = 0.025$ $\eta_{S,3} = 0.022$ $\eta_{S,4} = 0.02$ $\eta_{S,5} = 0.018$ $\eta_{S,6} = 0.016$ $\eta_{S,7} = 0.014$ $\eta_{S,8} = 0.013$ $\eta_{S,9} = 0.011$ $\eta_{S,10} = 0.01$ $\eta_{S,11} = 0.0089$ $\eta_{S,12} = 0.0079$ $\eta_{S,13} = 0.0071$ $\eta_{S,14} = 0.0063$ $\eta_{S,15} = 0.0056$ $\eta_{S,16} = 0.005$ $\eta_{S,17} = 0.0045$ $\eta_{S,18} = 0.004$ $\eta_{S,19} = 0.0035$ $\eta_{S,20} = 0.0032$ $\eta_{S,21} = 0.0028$ $\eta_{S,22} = 0.0025$ $\eta_{S,23} = 0.0022$ $\eta_{S,24} = 0.002$ $\eta_{S,25} = 0.0018$ $\eta_{S,26} = 0.0016$ $\eta_{S,27} = 0.0014$ $\eta_{S,28} = 0.0013$ $\eta_{S,29} = 0.0011$	$\eta_{S,1} = 0.028$ $\eta_{S,2} = 0.025$ $\eta_{S,3} = 0.022$ $\eta_{S,4} = 0.02$ $\eta_{S,5} = 0.018$ $\eta_{S,6} = 0.016$ $\eta_{S,7} = 0.014$ $\eta_{S,8} = 0.013$ $\eta_{S,9} = 0.011$ $\eta_{S,10} = 0.01$ $\eta_{S,11} = 0.0089$ $\eta_{S,12} = 0.0079$ $\eta_{S,13} = 0.0071$ $\eta_{S,14} = 0.0063$ $\eta_{S,15} = 0.0056$ $\eta_{S,16} = 0.005$ $\eta_{S,17} = 0.0045$ $\eta_{S,18} = 0.004$ $\eta_{S,19} = 0.0035$ $\eta_{S,20} = 0.0032$ $\eta_{S,21} = 0.0028$ $\eta_{S,22} = 0.0025$ $\eta_{S,23} = 0.0022$ $\eta_{S,24} = 0.002$ $\eta_{S,25} = 0.0018$ $\eta_{S,26} = 0.0016$ $\eta_{S,27} = 0.0014$ $\eta_{S,28} = 0.0013$ $\eta_{S,29} = 0.0011$	$\eta_{S,1} = 0.028$ $\eta_{S,2} = 0.025$ $\eta_{S,3} = 0.022$ $\eta_{S,4} = 0.02$ $\eta_{S,5} = 0.018$ $\eta_{S,6} = 0.016$ $\eta_{S,7} = 0.014$ $\eta_{S,8} = 0.013$ $\eta_{S,9} = 0.011$ $\eta_{S,10} = 0.01$ $\eta_{S,11} = 0.0089$ $\eta_{S,12} = 0.0079$ $\eta_{S,13} = 0.0071$ $\eta_{S,14} = 0.0063$ $\eta_{S,15} = 0.0056$ $\eta_{S,16} = 0.005$ $\eta_{S,17} = 0.0045$ $\eta_{S,18} = 0.004$ $\eta_{S,19} = 0.0035$ $\eta_{S,20} = 0.0032$ $\eta_{S,21} = 0.0028$ $\eta_{S,22} = 0.0025$ $\eta_{S,23} = 0.0022$ $\eta_{S,24} = 0.002$ $\eta_{S,25} = 0.0018$ $\eta_{S,26} = 0.0016$ $\eta_{S,27} = 0.0014$ $\eta_{S,28} = 0.0013$ $\eta_{S,29} = 0.0011$	$\eta_{S,1} = 0.028$ $\eta_{S,2} = 0.025$ $\eta_{S,3} = 0.022$ $\eta_{S,4} = 0.02$ $\eta_{S,5} = 0.018$ $\eta_{S,6} = 0.016$ $\eta_{S,7} = 0.014$ $\eta_{S,8} = 0.013$ $\eta_{S,9} = 0.011$ $\eta_{S,10} = 0.01$ $\eta_{S,11} = 0.0089$ $\eta_{S,12} = 0.0079$ $\eta_{S,13} = 0.0071$ $\eta_{S,14} = 0.0063$ $\eta_{S,15} = 0.0056$ $\eta_{S,16} = 0.005$ $\eta_{S,17} = 0.0045$ $\eta_{S,18} = 0.004$ $\eta_{S,19} = 0.0035$ $\eta_{S,20} = 0.0032$ $\eta_{S,21} = 0.0028$ $\eta_{S,22} = 0.0025$ $\eta_{S,23} = 0.0022$ $\eta_{S,24} = 0.002$ $\eta_{S,25} = 0.0018$ $\eta_{S,26} = 0.0016$ $\eta_{S,27} = 0.0014$ $\eta_{S,28} = 0.0013$ $\eta_{S,29} = 0.0011$	$\eta_{S,1} = 0.028$ $\eta_{S,2} = 0.025$ $\eta_{S,3} = 0.022$ $\eta_{S,4} = 0.02$ $\eta_{S,5} = 0.018$ $\eta_{S,6} = 0.016$ $\eta_{S,7} = 0.014$ $\eta_{S,8} = 0.013$ $\eta_{S,9} = 0.011$ $\eta_{S,10} = 0.01$ $\eta_{S,11} = 0.0089$ $\eta_{S,12} = 0.0079$ $\eta_{S,13} = 0.0071$ $\eta_{S,14} = 0.0063$ $\eta_{S,15} = 0.0056$ $\eta_{S,16} = 0.005$ $\eta_{S,17} = 0.0045$ $\eta_{S,18} = 0.004$ $\eta_{S,19} = 0.0035$ $\eta_{S,20} = 0.0032$ $\eta_{S,21} = 0.0028$ $\eta_{S,22} = 0.0025$ $\eta_{S,23} = 0.0022$ $\eta_{S,24} = 0.002$ $\eta_{S,25} = 0.0018$ $\eta_{S,26} = 0.0016$ $\eta_{S,27} = 0.0014$ $\eta_{S,28} = 0.0013$ $\eta_{S,29} = 0.0011$

	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6
	$\eta_{S,30}$ = 0.001 $\eta_{S,31}$ = 8.9×10^{-4} $\eta_{S,32}$ = 7.9×10^{-4} $\eta_{S,33}$ = 7.1×10^{-4}	$\eta_{S,30}$ = 0.001 $\eta_{S,31}$ = 8.9×10^{-4} $\eta_{S,32}$ = 7.9×10^{-4} $\eta_{S,33}$ = 7.1×10^{-4}	$\eta_{S,30}$ = 0.001 $\eta_{S,31}$ = 8.9×10^{-4} $\eta_{S,32}$ = 7.9×10^{-4} $\eta_{S,33}$ = 7.1×10^{-4}	$\eta_{S,30}$ = 0.001 $\eta_{S,31}$ = 8.9×10^{-4} $\eta_{S,32}$ = 7.9×10^{-4} $\eta_{S,33}$ = 7.1×10^{-4}	$\eta_{S,30}$ = 0.001 $\eta_{S,31}$ = 8.9×10^{-4} $\eta_{S,32}$ = 7.9×10^{-4} $\eta_{S,33}$ = 7.1×10^{-4}	$\eta_{S,30}$ = 0.001 $\eta_{S,31}$ = 8.9×10^{-4} $\eta_{S,32}$ = 7.9×10^{-4} $\eta_{S,33}$ = 7.1×10^{-4}
(20b) Damping factor for transmission loss $\Delta TL = \begin{cases} 0 & for\ D > 0.15 \\ -16660 \cdot D^3 + 6370 \cdot D^2 - 813 \cdot D + 35.8 & for\ 0.05 \le D \le 0.15 \\ 9 & for\ D < 0.05 \end{cases}$	ΔTL = 1.5 dB	ΔTL = 1.5 dB	ΔTL = 1.5 dB	ΔTL = 0 dB	ΔTL = 0 dB	ΔTL = 1.5 dB
(20a) Frequency dependent transmission loss (third octave bands: 12,5 Hz – 20 000 Hz) $\mathrm{TL}(f_i) = 10\ log_{10}\left[\frac{\left(8{,}25 \times 10^{-7}\right)\left(\frac{c_2}{t_S f_i}\right)^2 \cdot G_x(f_i)}{\left(\frac{\rho_2\ c_2 + 2 \cdot \pi \cdot t_S \cdot f_i \cdot \rho_s \cdot \eta_s(f_i)}{415\, G_y(f_i)} + 1\right)}\left(\frac{p_a}{p_s}\right)\right] - \Delta TL$	TL_1 = -93 dB TL_2 = -90.9 dB TL_3 = -89 dB TL_4 = -87.1 dB TL_5 = -85.2 dB TL_6 = -83.1 dB TL_7 = -81.2 dB TL_8 = -79.3 dB TL_9 = -77.3 dB TL_{10} = -75.4dB TL_{11} = -73.6dB TL_{12} = -71.5dB TL_{13} = -69.7dB TL_{14} = -67.8dB TL_{15} = -65.9dB TL_{16} = -64 dB TL_{17} = -62.2dB TL_{18} = -60.3dB TL_{19} = -58.4dB TL_{20} = -56.7dB TL_{21} = -54.9dB TL_{22} = -53 dB TL_{23} = -51.2dB TL_{24} = -49.5dB TL_{25} = -49.1dB TL_{26} = -50.9dB TL_{27} = -52.7dB TL_{28} = -54.4dB TL_{29} = -56.4dB TL_{30} = -58.6dB TL_{31} = -60.9dB TL_{32} = -63.4dB TL_{33} = -65.6dB	TL_1 = -92.9 dB TL_2 = -90.8 dB TL_3 = -88.9 dB TL_4 = -87 dB TL_5 = -85 dB TL_6 = -83 dB TL_7 = -81.1 dB TL_8 = -79.2 dB TL_9 = -77.2 dB TL_{10} = -75.3dB TL_{11} = -73.4dB TL_{12} = -71.4dB TL_{13} = -69.6dB TL_{14} = -67.7dB TL_{15} = -65.8dB TL_{16} = -63.9dB TL_{17} = -62.1dB TL_{18} = -60.2dB TL_{19} = -58.3dB TL_{20} = -56.5dB TL_{21} = -54.8dB TL_{22} = -52.9dB TL_{23} = -51.2dB TL_{24} = -49.4dB TL_{25} = -49.0dB TL_{26} = -50.9dB TL_{27} = -52.6dB TL_{28} = -54.4dB TL_{29} = -56.3dB TL_{30} = -58.5dB TL_{31} = -60.8dB TL_{32} = -63.3dB TL_{33} = -65.6dB	TL_1 = -91.8 dB TL_2 = -89.7 dB TL_3 = -87.8 dB TL_4 = -85.9 dB TL_5 = -83.9 dB TL_6 = -81.9 dB TL_7 = -80 dB TL_8 = -78.1 dB TL_9 = -76.1 dB TL_{10} = -74.3dB TL_{11} = -72.4dB TL_{12} = -70.4dB TL_{13} = -68.6dB TL_{14} = -66.8dB TL_{15} = -64.9dB TL_{16} = -63 dB TL_{17} = -61.3dB TL_{18} = -59.4dB TL_{19} = -57.6dB TL_{20} = -55.8dB TL_{21} = -54.1dB TL_{22} = -52.2dB TL_{23} = -50.5dB TL_{24} = -48.9dB TL_{25} = -48.5dB TL_{26} = -50.3dB TL_{27} = -52.1dB TL_{28} = -53.9dB TL_{29} = -55.9dB TL_{30} = -58.2dB TL_{31} = -60.4dB TL_{32} = -63 dB TL_{33} = -65.3dB	TL_1 = -89.8 dB TL_2 = -87.7 dB TL_3 = -85.8 dB TL_4 = -84 dB TL_5 = -82 dB TL_6 = -80 dB TL_7 = -78.1 dB TL_8 = -76.2 dB TL_9 = -74.2 dB TL_{10} = -72.4dB TL_{11} = -70.6dB TL_{12} = -68.6dB TL_{13} = -66.8dB TL_{14} = -65 dB TL_{15} = -63.1dB TL_{16} = -61.2dB TL_{17} = -59.4dB TL_{18} = -57.6dB TL_{19} = -55.8dB TL_{20} = -54.1dB TL_{21} = -52.3dB TL_{22} = -50.5dB TL_{23} = -48.8dB TL_{24} = -47.1dB TL_{25} = -46.8dB TL_{26} = -48.6dB TL_{27} = -50.4dB TL_{28} = -52.2dB TL_{29} = -54.2dB TL_{30} = -56.5dB TL_{31} = -58.8dB TL_{32} = -61.3dB TL_{33} = -63.7dB	TL_1 = -86.1 dB TL_2 = -84 dB TL_3 = -82.2 dB TL_4 = -80.4 dB TL_5 = -78.5 dB TL_6 = -76.6 dB TL_7 = -74.8 dB TL_8 = -73 dB TL_9 = -71.1 dB TL_{10} = -69.4dB TL_{11} = -67.6dB TL_{12} = -65.8dB TL_{13} = -64.1dB TL_{14} = -62.4dB TL_{15} = -60.7dB TL_{16} = -58.9dB TL_{17} = -57.3dB TL_{18} = -55.6dB TL_{19} = -53.8dB TL_{20} = -52.2dB TL_{21} = -50.6dB TL_{22} = -48.9dB TL_{23} = -47.3dB TL_{24} = -45.8dB TL_{25} = -45.5dB TL_{26} = -47.5dB TL_{27} = -49.3dB TL_{28} = -51.3dB TL_{29} = -53.3dB TL_{30} = -55.7dB TL_{31} = -58.1dB TL_{32} = -60.7dB TL_{33} = -63.1dB	TL_1 = -92.9 dB TL_2 = 90.8 dB TL_3 = -89 dB TL_4 = -87.2 dB TL_5 = -85.3 dB TL_6 = -83.4 dB TL_7 = -81.7 dB TL_8 = -79.8 dB TL_9 = -77.9 dB TL_{10} = -76.2dB TL_{11} = -74.5dB TL_{12} = -72.6dB TL_{13} = -70.9dB TL_{14} = -69.2dB TL_{15} = -67.5dB TL_{16} = -65.7dB TL_{17} = -64.1dB TL_{18} = -62.4dB TL_{19} = -60.6dB TL_{20} = -59 dB TL_{21} = -57.5dB TL_{22} = -55.7dB TL_{23} = -54.1dB TL_{24} = -52.6dB TL_{25} = -51 dB TL_{26} = -49.7dB TL_{27} = -51.5dB TL_{28} = -53.5dB TL_{29} = -55.5dB TL_{30} = -57.4dB TL_{31} = -59.6dB TL_{32} = -62.2dB TL_{33} = -64.6dB
(24) Frequency dependent external sound-pressure level (third octave bands: 12.5 Hz – 20000 Hz) $L_{pe,1m}(f_i) = L_{pi}(f_i) + TL(f_i) - 10\log\left(\frac{D_i + 2\,t_S + 2}{D_i + 2\,t_S}\right)$	$L_{pe,1m,1}$ = 2 dB $L_{pe,1m,2}$ = 6 dB $L_{pe,1m,3}$ = 9 dB $L_{pe,1m,4}$ = 13 dB $L_{pe,1m,5}$ = 17 dB $L_{pe,1m,6}$ = 20 dB $L_{pe,1m,7}$ = 24 dB $L_{pe,1m,8}$ = 27 dB $L_{pe,1m,9}$ = 31 dB $L_{pe,1m,10}$ =35dB $L_{pe,1m,11}$ =38dB $L_{pe,1m,12}$ =42dB $L_{pe,1m,13}$ =46dB $L_{pe,1m,14}$ =49dB $L_{pe,1m,15}$ =53dB $L_{pe,1m,16}$ =56dB $L_{pe,1m,17}$ =60dB $L_{pe,1m,18}$ =63dB $L_{pe,1m,19}$ =67dB $L_{pe,1m,20}$ =70dB $L_{pe,1m,21}$ =73dB $L_{pe,1m,22}$ =77dB $L_{pe,1m,23}$ =80dB $L_{pe,1m,24}$ =83dB $L_{pe,1m,25}$ =84dB $L_{pe,1m,26}$ =83dB $L_{pe,1m,27}$ =82dB $L_{pe,1m,28}$ =81dB $L_{pe,1m,29}$ =79dB $L_{pe,1m,30}$ =77dB $L_{pe,1m,31}$ =74dB $L_{pe,1m,32}$ =70dB $L_{pe,1m,33}$ =67dB	$L_{pe,1m,1}$ = 3 dB $L_{pe,1m,2}$ = 7 dB $L_{pe,1m,3}$ = 10 dB $L_{pe,1m,4}$ = 14 dB $L_{pe,1m,5}$ = 18 dB $L_{pe,1m,6}$ = 21 dB $L_{pe,1m,7}$ = 25 dB $L_{pe,1m,8}$ = 28 dB $L_{pe,1m,9}$ = 32 dB $L_{pe,1m,10}$ =36dB $L_{pe,1m,11}$ =39dB $L_{pe,1m,12}$ =43dB $L_{pe,1m,13}$ =47dB $L_{pe,1m,14}$ =50dB $L_{pe,1m,15}$ =54dB $L_{pe,1m,16}$ =57dB $L_{pe,1m,17}$ =61dB $L_{pe,1m,18}$ =64dB $L_{pe,1m,19}$ =68dB $L_{pe,1m,20}$ =71dB $L_{pe,1m,21}$ =74dB $L_{pe,1m,22}$ =78dB $L_{pe,1m,23}$ =81dB $L_{pe,1m,24}$ =84dB $L_{pe,1m,25}$ =85dB $L_{pe,1m,26}$ =84dB $L_{pe,1m,27}$ =83dB $L_{pe,1m,28}$ =82dB $L_{pe,1m,29}$ =80dB $L_{pe,1m,30}$ =78dB $L_{pe,1m,31}$ =75dB $L_{pe,1m,32}$ =72dB $L_{pe,1m,33}$ =68dB	$L_{pe,1m,1}$ = 7 dB $L_{pe,1m,2}$ = 11 dB $L_{pe,1m,3}$ = 15 dB $L_{pe,1m,4}$ = 18 dB $L_{pe,1m,5}$ = 22 dB $L_{pe,1m,6}$ = 26 dB $L_{pe,1m,7}$ = 29 dB $L_{pe,1m,8}$ = 33 dB $L_{pe,1m,9}$ = 37 dB $L_{pe,1m,10}$ =40dB $L_{pe,1m,11}$ =44dB $L_{pe,1m,12}$ =48dB $L_{pe,1m,13}$ =51dB $L_{pe,1m,14}$ =54dB $L_{pe,1m,15}$ =58dB $L_{pe,1m,16}$ =62dB $L_{pe,1m,17}$ =65dB $L_{pe,1m,18}$ =69dB $L_{pe,1m,19}$ =72dB $L_{pe,1m,20}$ =75dB $L_{pe,1m,21}$ =79dB $L_{pe,1m,22}$ =82dB $L_{pe,1m,23}$ =85dB $L_{pe,1m,24}$ =88dB $L_{pe,1m,25}$ =90dB $L_{pe,1m,26}$ =89dB $L_{pe,1m,27}$ =88dB $L_{pe,1m,28}$ =87dB $L_{pe,1m,29}$ =86dB $L_{pe,1m,30}$ =84dB $L_{pe,1m,31}$ =81dB $L_{pe,1m,32}$ =78dB $L_{pe,1m,33}$ =75dB	$L_{pe,1m,1}$ = 3 dB $L_{pe,1m,2}$ = 7 dB $L_{pe,1m,3}$ = 10 dB $L_{pe,1m,4}$ = 14 dB $L_{pe,1m,5}$ = 18 dB $L_{pe,1m,6}$ = 21 dB $L_{pe,1m,7}$ = 25 dB $L_{pe,1m,8}$ = 29 dB $L_{pe,1m,9}$ = 32 dB $L_{pe,1m,10}$ =36dB $L_{pe,1m,11}$ =39dB $L_{pe,1m,12}$ =43dB $L_{pe,1m,13}$ =47dB $L_{pe,1m,14}$ =50dB $L_{pe,1m,15}$ =54dB $L_{pe,1m,16}$ =57dB $L_{pe,1m,17}$ =61dB $L_{pe,1m,18}$ =64dB $L_{pe,1m,19}$ =68dB $L_{pe,1m,20}$ =71dB $L_{pe,1m,21}$ =74dB $L_{pe,1m,22}$ =78dB $L_{pe,1m,23}$ =81dB $L_{pe,1m,24}$ =84dB $L_{pe,1m,25}$ =86dB $L_{pe,1m,26}$ =86dB $L_{pe,1m,27}$ =85dB $L_{pe,1m,28}$ =84dB $L_{pe,1m,29}$ =83dB $L_{pe,1m,30}$ =82dB $L_{pe,1m,31}$ =80dB $L_{pe,1m,32}$ =77dB $L_{pe,1m,33}$ =75dB	$L_{pe,1m,1}$ = 11 dB $L_{pe,1m,2}$ = 15 dB $L_{pe,1m,3}$ = 19 dB $L_{pe,1m,4}$ = 22 dB $L_{pe,1m,5}$ = 26 dB $L_{pe,1m,6}$ = 29 dB $L_{pe,1m,7}$ = 33 dB $L_{pe,1m,8}$ = 36 dB $L_{pe,1m,9}$ = 40 dB $L_{pe,1m,10}$ =43dB $L_{pe,1m,11}$ =47dB $L_{pe,1m,12}$ =50dB $L_{pe,1m,13}$ =54dB $L_{pe,1m,14}$ =57dB $L_{pe,1m,15}$ =61dB $L_{pe,1m,16}$ =64dB $L_{pe,1m,17}$ =67dB $L_{pe,1m,18}$ =71dB $L_{pe,1m,19}$ =74dB $L_{pe,1m,20}$ =77dB $L_{pe,1m,21}$ =80dB $L_{pe,1m,22}$ =83dB $L_{pe,1m,23}$ =86dB $L_{pe,1m,24}$ =89dB $L_{pe,1m,25}$ =90dB $L_{pe,1m,26}$ =89dB $L_{pe,1m,27}$ =87dB $L_{pe,1m,28}$ =86dB $L_{pe,1m,29}$ =84dB $L_{pe,1m,30}$ =81dB $L_{pe,1m,31}$ =78dB $L_{pe,1m,32}$ =74dB $L_{pe,1m,33}$ =70dB	Use $L_{piS}(f_i)$ instead of $L_{pi}(f_i)$ $L_{pe,1m,1}$ = 13 dB $L_{pe,1m,2}$ = 17 dB $L_{pe,1m,3}$ = 20 dB $L_{pe,1m,4}$ = 24 dB $L_{pe,1m,5}$ = 27 dB $L_{pe,1m,6}$ = 31 dB $L_{pe,1m,7}$ = 35 dB $L_{pe,1m,8}$ = 38 dB $L_{pe,1m,9}$ = 42 dB $L_{pe,1m,10}$ =45dB $L_{pe,1m,11}$ =48dB $L_{pe,1m,12}$ =52dB $L_{pe,1m,13}$ =55dB $L_{pe,1m,14}$ =58dB $L_{pe,1m,15}$ =61dB $L_{pe,1m,16}$ =64dB $L_{pe,1m,17}$ =66dB $L_{pe,1m,18}$ =69dB $L_{pe,1m,19}$ =71dB $L_{pe,1m,20}$ =74dB $L_{pe,1m,21}$ =76dB $L_{pe,1m,22}$ =78dB $L_{pe,1m,23}$ =80dB $L_{pe,1m,24}$ =82dB $L_{pe,1m,25}$ =85dB $L_{pe,1m,26}$ =87dB $L_{pe,1m,27}$ =85dB $L_{pe,1m,28}$ =84dB $L_{pe,1m,29}$ =82dB $L_{pe,1m,30}$ =80dB $L_{pe,1m,31}$ =77dB $L_{pe,1m,32}$ =74dB $L_{pe,1m,33}$ =70dB
(25) A-weighted sound-pressure level 1 m from pipe wall $L_{pAe,1m} = 10 \cdot Log_{10}\left(\sum_{i=1}^{N=33} 10^{\frac{L_{pe,1m}(f_i) + \Delta L_A(f_i)}{10}}\right)$	$\Delta L_A(f_i)$ see 5.6 ⇒ $L_{pAe,1m}$ = 92 dB(A)	$\Delta L_A(f_i)$ see 5.6 ⇒ $L_{pAe,1m}$ = 93 dB(A)	$\Delta L_A(f_i)$ see 5.6 ⇒ $L_{pAe,1m}$ = 98 dB(A)	$\Delta L_A(f_i)$ see 5.6 ⇒ $L_{pAe,1m}$ = 94 dB(A)	$\Delta L_A(f_i)$ see 5.6 ⇒ $L_{pAe,1m}$ = 97 dB(A)	$\Delta L_A(f_i)$ see 5.6 ⇒ $L_{pAe,1m}$ = 94 dB(A)

A.3 Calculation example 7

Given data

Valve

Single-seat globe valve (with cage) installed flow to open

Valve size:	*DN 200*
Valve outlet diameter:	D = 0,200 m
Required C_v:	C_v = 81,5
Number of independent and identical flow passages:	N_o = 432
Total flow area of last stage:	A_n = 6,44 × 10^{-3} m^2
Hydraulic diameter:	d_H = 0,0025 m
Liquid pressure recovery factor for last stage:	F_{Ln} = 0,98

Pipe

Inlet nominal pipe size:	DN 200
Outlet nominal pipe size:	DN 200
Pipe wall thickness:	t_S = 0,008 m
Internal pipe diameter:	D_i = 0,200 m
Speed of sound in pipe:	c_S = 5 000 m/s
Density of pipe material:	ρ_S = 8 000 kg/m³

Other

Speed of sound in air:	c_o = 343 m/s
Density of air:	ρ_o = 1,293 kg/m^3
Actual atmospheric pressure:	p_a = 1,013 25 bar = 1,013 25 × 10^5 Pa
Standard atmospheric pressure:	p_s = 1,013 25 bar = 1,013 25 × 10^5 Pa

Definitions

Index	1	2	3	4	5	6	7	8	9	10	11
Frequency [Hz]	12.5	16	20	25	31.5	40	50	63	80	100	125
Index	12	13	14	15	16	17	18	19	20	21	22
Frequency [Hz]	160	200	250	315	400	500	630	800	1000	1250	1600
Index	23	24	25	26	27	28	29	30	31	32	33
Frequency [Hz]	2000	2500	3150	4000	5000	6300	8000	1000 0	1250 0	1600 0	2000 0

Table A.2 – Calculation: example 7

	Example 7
Type fluid: vapour	
Mass flow rate	$\dot{m}$ = 23.1 kg/s
Valve inlet absolute pressure	p_1 = 70 bar = 7.0 x 10^6 Pa
Valve outlet absolute pressure	p_2 = 14 bar = 1.4 x 10^6 Pa
Inlet density	ρ_1 = 55.3 kg/m³
Inlet absolute temperature	T_1 = 290 K
Specific heat ratio	γ = 1.31
Molecular mass	M = 19.0 kg/kmol
(27) Flow coefficient for last stage of multistage trim $C_n = N_{16} A_n$	C_n = 315
Determination of absolute stagnation pressure at last stage of multistage valve	p_1/p_2 = 5 > 2 ⇒ $p_n/p_2 < 2$ ⇒ Calculation of eq. (28a) is necessary
(28a) Absolute stagnation pressure at last stage of multistage valve $p_n = \sqrt{\left(\frac{p_1 C}{1{,}155\, C_n}\right)^2 + p_2^{\,2}}$	p_n = 2.1 x 10^6 Pa ⇒ p_n/p_2 = 1.5 < 2 ⇒ The use of Equation (28a) is appropriate
(1) Differential pressure ratio $x = \frac{p_1 - p_2}{p_1}$	Use $p_1 = p_n$ ⇒ x = 0.334
(2) Absolute vena contracta pressure at subsonic flow conditions $p_{vc} = p_1 \cdot \left(1 - \frac{x}{F_{Ln}^{\,2}}\right)$	p_{vc} = 1371038 Pa
(3) Vena contracta differential pressure ratio at critical flow conditions $x_{vcc} = 1 - \left(\frac{2}{\gamma+1}\right)^{\gamma/(\gamma-1)}$	x_{vcc} = 0.456
(4) Differential pressure ratio at critical flow conditions $x_C = F_{Ln}^{\,2} x_{vcc}$	x_C = 0.438
(5) Recovery correction factor $\alpha \equiv \frac{1 - x_{vcc}}{1 - x_C}$	α = 0.968
(6) Differential pressure ratio at break point $x_B = 1 - \frac{1}{\alpha}\left(\frac{1}{\gamma}\right)^{\gamma/(\gamma-1)}$	x_B = 0.67
(7) Differential pressure ratio where region of constant acoustical efficiency begins $x_{CE} = 1 - \frac{1}{22\,\alpha}$	x_{CE} = 0.953
Regime definition Regime I If $x \le x_C$ Regime II If $x_C < x \le x_{vcc}$ Regime III If $x_{vcc} < x \le x_B$ Regime IV If $x_B < x \le x_{CE}$ Regime V If $x_{CE} < x$	$x \le x_C$ ⇒ Regime I
Area of a single flow passage $A = \frac{A_n}{N_o}$	A = 1.5 x 10^{-5} m²

	Example 7
(8c) Diameter of a circular orifice $d_o = \sqrt{\frac{4\ N_o\ A}{\pi}}$	d_o = 0.091 m
(8a) Valve style modifier $F_d = \frac{d_H}{d_o}$	F_d = 0.028
(9) Jet diameter $D_j = N_{14}\ F_d \sqrt{C_n\ F_{Ln}}$	N_{14} = 4.6 x 10^{-3} ⇒ D_j = 0.0022 m
Calculations for Regime I	
(Table 3) Stream power of mass flow $W_m = \frac{\dot{m}(M_{vc}c_{vc})^2}{2}$	W_m = 1.19 x 10^6 W
(Table 3) Vena contracta absolute temperature $T_{vc} = T_1\left(1-\frac{x}{F_{Ln}^{\ 2}}\right)^{(\gamma-1)/\gamma}$	T_{vc} = 262 K
(Table 3) Speed of sound in the vena contracta $c_{vc} = \sqrt{\gamma \frac{p_1}{\rho_1}\left(1-\frac{x}{F_{Ln}^{\ 2}}\right)^{(\gamma-1)/\gamma}}$	Use $p_1 = p_n$ and $\rho_1 = \rho_n$ ⇒ c_{vc} = 387.1m/s
(Table 3) Mach number at vena contracta $M_{vc} = \sqrt{\left(\frac{2}{\gamma-1}\right)\left[\left(1-\frac{x}{F_L^{\ 2}}\right)^{(1-\gamma)/\gamma}-1\right]}$	M_{vc} = 0.829
(Table 3) Acoustical efficiency factor $\eta_1 = \left(1 \times 10^{A_\eta}\right) F_{Ln}^{\ 2} \cdot M_{vc}^{\ 3}$	A_η = -4.8 ⇒ η_1 = 8.7 x 10^{-6}
(11) Sound power $W_a = \eta_1\ W_m$	W_a = 10.3 W
(Table 3) Peak frequency $f_p = \frac{Stp \cdot M_{vc} \cdot c_{vc}}{D_j}$	St_p = 0.1 ⇒ f_p = 14381 Hz
Noise calculations	
(13) Outlet density $\rho_2 = \rho_1\left(\frac{p_2}{p_1}\right)$	ρ_2 = 11.1 kg/m³
(14) Speed of sound at downstream conditions $c_2 = \sqrt{\frac{\gamma\ R\ T_2}{M}}$	R = 8314 J/kmol x K ⇒ c_2 = 408 m/s
(15) Mach number at valve outlet $M_o = \frac{4\ \dot{m}}{\pi\ D^2\ \rho_2\ c_2}$	M_o = 0.16 <0.3 ⇒ calculations are appropriate
(17) Mach number in downstream pipe $M_2 = \frac{4\ \dot{m}}{\pi\ D_i^{\ 2}\ \rho_2 c_2} \quad < 0.3$	M_2 = 0.16 <0.3 ⇒ M_2 = 0.16
(16) Correction for Mach number $L_g = 16 \log_{10}\left(\frac{1}{1-M_2}\right)$	L_G = 1.2 dB
(18) Overall internal sound-pressure level $L_{pi} = 10\ log_{10}\left[\frac{\left(3{,}2 \times 10^9\right) W_a\ \rho_2\ c_2}{D_i^{\ 2}}\right] + L_g$	L_{pi} = 156.9 dB
(19) Frequency dependent internal sound-pressure level (third octave bands: 12.5 Hz – 20000 Hz) $L_{pi}(f_i) = L_{pi} - 8 - 10 \cdot \log\left\{\left[1+\left(\frac{f_i}{2 \cdot f_p}\right)^{2.5}\right] \cdot \left[1+\left(\frac{f_p}{2 \cdot f_i}\right)^{1.7}\right]\right\}$	$L_{pi,1}$ = 102 dB $L_{pi,2}$ = 104 dB $L_{pi,3}$ = 105 dB $L_{pi,4}$ = 107 dB $L_{pi,5}$ = 109 dB $L_{pi,6}$ = 111 dB $L_{pi,7}$ = 112 dB $L_{pi,8}$ = 114 dB $L_{pi,9}$ = 116 dB $L_{pi,10}$ = 117 dB $L_{pi,11}$ = 119 dB $L_{pi,12}$ = 121 dB $L_{pi,13}$ = 122 dB

	Example 7
	$L_{pi,14}$ = 124 dB $L_{pi,15}$ = 126 dB $L_{pi,16}$ = 128 dB $L_{pi,17}$ = 129 dB $L_{pi,18}$ = 131 dB $L_{pi,19}$ = 133 dB $L_{pi,20}$ = 134 dB $L_{pi,21}$ = 136 dB $L_{pi,22}$ = 138 dB $L_{pi,23}$ = 139 dB $L_{pi,24}$ = 140 dB $L_{pi,25}$ = 142 dB $L_{pi,26}$ = 143 dB $L_{pi,27}$ = 144 dB $L_{pi,28}$ = 145 dB $L_{pi,29}$ = 146 dB $L_{pi,30}$ = 147 dB $L_{pi,31}$ = 147 dB $L_{pi,32}$ = 147 dB $L_{pi,33}$ = 147 dB
Note	M_0 <0.3 $\Rightarrow$ Calculation of eqs. (54)-(63) is not necessary
(21) Ring frequency $f_r = \frac{c_s}{\pi D_i}$	c_S = 5000 m/s $\Rightarrow$ f_r = 7958 Hz
(22) Internal coincidence pipe frequency $f_o = \frac{f_r}{4}\left(\frac{c_2}{c_a}\right)$	c_a = 343 m/s $\Rightarrow$ f_0 = 2365 Hz
(23) External coincidence frequency $f_g = \frac{\sqrt{3}\,(c_a)^2}{\pi\, t_s (c_s)}$	f_g = 1622 Hz
(Table 6) Frequency factor G_x (third octave bands: 12,5 Hz – 20 000 Hz) $G_x(f_i) = \begin{cases} \left(\frac{f_o}{f_r}\right)^{2/3}\left(\frac{f_i}{f_o}\right)^4 & for\ f_i < f_0 \\ \left(\frac{f_i}{f_r}\right)^{1/2} & for\ f_i \geq f_0\ and\ f_i < f_r \\ 1 & for\ f_i \geq f_0\ and\ f_i \geq f_r \end{cases}$	$G_{x,1} = 3.5 \times 10^{-10}$ $G_{x,2} = 9.3 \times 10^{-10}$ $G_{x,3} = 2.3 \times 10^{-9}$ $G_{x,4} = 5.6 \times 10^{-9}$ $G_{x,5} = 1.4 \times 10^{-9}$ $G_{x,6} = 3.6 \times 10^{-8}$ $G_{x,7} = 8.9 \times 10^{-8}$ $G_{x,8} = 2.2 \times 10^{-7}$ $G_{x,9} = 5.8 \times 10^{-7}$ $G_{x,10} = 1.4 \times 10^{-7}$ $G_{x,11} = 3.5 \times 10^{-6}$ $G_{x,12} = 9.3 \times 10^{-6}$ $G_{x,13} = 2.3 \times 10^{-5}$ $G_{x,14} = 5.6 \times 10^{-5}$ $G_{x,15} = 1.4 \times 10^{-4}$ $G_{x,16} = 3.6 \times 10^{-4}$ $G_{x,17} = 8.9 \times 10^{-4}$ $G_{x,18}$ = 0.0022 $G_{x,19}$ = 0.0058 $G_{x,20}$ = 0.014 $G_{x,21}$ = 0.035 $G_{x,22}$ = 0.093 $G_{x,23}$ = 0.23 $G_{x,24}$ = 0.56 $G_{x,25}$ = 0.63 $G_{x,26}$ = 0.71 $G_{x,27}$ = 0.79 $G_{x,28}$ = 0.89 $G_{x,29}$ = 1 $G_{x,30}$ = 1 $G_{x,31}$ = 1 $G_{x,32}$ = 1 $G_{x,33}$ = 1
(Table 6) Frequency factor G_y (third octave bands: 12,5 Hz – 20 000 Hz) $G_y(f_i) = \begin{cases} \left(\frac{f_o}{f_g}\right) & for\ f_i < f_0\ and\ f_0 < f_g \\ 1 & for\ f_i < f_0\ and\ f_0 \geq f_g \\ \left(\frac{f_i}{f_g}\right) & for\ f_i \geq f_0\ and\ f_i < f_g \\ 1 & for\ f_i \geq f_0\ and\ f_i \geq f_g \end{cases}$	$G_{y,1}$ = 1 $G_{y,2}$ = 1 $G_{y,3}$ = 1 $G_{y,4}$ = 1 $G_{y,5}$ = 1 $G_{y,6}$ = 1 $G_{y,7}$ = 1 $G_{y,8}$ = 1 $G_{y,9}$ = 1 $G_{y,10}$ = 1 $G_{y,11}$ = 1 $G_{y,12}$ = 1 $G_{y,13}$ = 1 $G_{y,14}$ = 1 $G_{y,15}$ = 1 $G_{y,16}$ = 1

	Example 7
	$G_{y,17} = 1$ $G_{y,18} = 1$ $G_{y,19} = 1$ $G_{y,20} = 1$ $G_{y,21} = 1$ $G_{y,22} = 1$ $G_{y,23} = 1$ $G_{y,24} = 1$ $G_{y,25} = 1$ $G_{y,26} = 1$ $G_{y,27} = 1$ $G_{y,28} = 1$ $G_{y,29} = 1$ $G_{y,30} = 1$ $G_{y,31} = 1$ $G_{y,32} = 1$ $G_{y,33} = 1$
(20c) Frequency-dependent structural loss factor (third octave bands: 12,5 Hz– 20 000 Hz) $\eta_s(f_i) = \sqrt{\dfrac{f_s}{100 f_i}}$	$\eta_{S,1} = 0.028$ $\eta_{S,2} = 0.025$ $\eta_{S,3} = 0.022$ $\eta_{S,4} = 0.02$ $\eta_{S,5} = 0.018$ $\eta_{S,6} = 0.016$ $\eta_{S,7} = 0.014$ $\eta_{S,8} = 0.013$ $\eta_{S,9} = 0.011$ $\eta_{S,10} = 0.01$ $\eta_{S,11} = 0.0089$ $\eta_{S,12} = 0.0079$ $\eta_{S,13} = 0.0071$ $\eta_{S,14} = 0.0063$ $\eta_{S,15} = 0.0056$ $\eta_{S,16} = 0.005$ $\eta_{S,17} = 0.0045$ $\eta_{S,18} = 0.004$ $\eta_{S,19} = 0.0035$ $\eta_{S,20} = 0.0032$ $\eta_{S,21} = 0.0028$ $\eta_{S,22} = 0.0025$ $\eta_{S,23} = 0.0022$ $\eta_{S,24} = 0.002$ $\eta_{S,25} = 0.0018$ $\eta_{S,26} = 0.0016$ $\eta_{S,27} = 0.0014$ $\eta_{S,28} = 0.0013$ $\eta_{S,29} = 0.0011$ $\eta_{S,30} = 0.001$ $\eta_{S,31} = 8.9 \times 10^{-4}$ $\eta_{S,32} = 7.9 \times 10^{-4}$ $\eta_{S,33} = 7.1 \times 10^{-4}$
(20b) Damping factor for transmission loss $\Delta TL = \begin{cases} 0 & for\ D > 0.15 \\ -16660 \cdot D^3 + 6370 \cdot D^2 \\ -813 \cdot D + 35.8 & for\ 0.05 \le D \le 0.15 \\ 9 & for\ D < 0.05 \end{cases}$	$\Delta TL = 0$ dB
(20a) Frequency dependent transmission loss (third octave bands: 12,5 Hz – 20 000 Hz) $\mathrm{TL}(f_i) = 10\,log_{10}\left[\dfrac{\left(8{,}25 \times 10^{-7}\right)\left(\dfrac{c_2}{t_s f_i}\right)^2 \cdot G_x(f_i)}{\left(\dfrac{\rho_2\, c_2 + 2 \cdot \pi \cdot t_S \cdot f_i \cdot \rho_s \cdot \eta_s(f_i)}{415\, G_y(f_i)} + 1\right)}\left(\dfrac{p_a}{p_s}\right)\right] - \Delta TL$	$TL_1 = -94.1$ dB $TL_2 = -92$ dB $TL_3 = -90$ dB $TL_4 = -88.1$ dB $TL_5 = -86.1$ dB $TL_6 = -84.1$ dB $TL_7 = -82.2$ dB $TL_8 = -80.2$ dB $TL_9 = -78.1$ dB $TL_{10} = -76.2$ dB $TL_{11} = -74.3$ dB $TL_{12} = -72.2$ dB $TL_{13} = -70.4$ dB $TL_{14} = -68.5$ dB $TL_{15} = -66.5$ dB $TL_{16} = -64.5$ dB $TL_{17} = -62.6$ dB $TL_{18} = -60.7$ dB $TL_{19} = -58.7$ dB $TL_{20} = -56.9$ dB $TL_{21} = -55.1$ dB $TL_{22} = -53$ dB $TL_{23} = -51.2$ dB $TL_{24} = -49.4$ dB

	Example 7
	TL_{25} = -51.1 dB TL_{26} = -52.8 dB TL_{27} = -54.4 dB TL_{28} = -56.1 dB TL_{29} = -57.9 dB TL_{30} = -60 dB TL_{31} = -62.2 dB TL_{32} = -64.6 dB TL_{33} = -66.8 dB
(24) Frequency dependent external sound-pressure level (third octave bands: 12,5 Hz – 20 000 Hz) $L_{pe,1m}(f_i) = L_{pi}(f_i) + TL(f_i)$ $-10\log\left(\frac{D_i + 2\,t_S + 2}{D_i + 2\,t_S}\right)$	$L_{pe,1m,1}$ = -2 dB $L_{pe,1m,2}$ = 2 dB $L_{pe,1m,3}$ = 5 dB $L_{pe,1m,4}$ = 9 dB $L_{pe,1m,5}$ = 13 dB $L_{pe,1m,6}$ = 16 dB $L_{pe,1m,7}$ = 20 dB $L_{pe,1m,8}$ = 24 dB $L_{pe,1m,9}$ = 27 dB $L_{pe,1m,10}$ = 31 dB $L_{pe,1m,11}$ = 35 dB $L_{pe,1m,12}$ = 38 dB $L_{pe,1m,13}$ = 42 dB $L_{pe,1m,14}$ = 46 dB $L_{pe,1m,15}$ = 49 dB $L_{pe,1m,16}$ = 53 dB $L_{pe,1m,17}$ = 56 dB $L_{pe,1m,18}$ = 60 dB $L_{pe,1m,19}$ = 64 dB $L_{pe,1m,20}$ = 67 dB $L_{pe,1m,21}$ = 71 dB $L_{pe,1m,22}$ = 74 dB $L_{pe,1m,23}$ = 78 dB $L_{pe,1m,24}$ = 81 dB $L_{pe,1m,25}$ = 81 dB $L_{pe,1m,26}$ = 80 dB $L_{pe,1m,27}$ = 80 dB $L_{pe,1m,28}$ = 79 dB $L_{pe,1m,29}$ = 78 dB $L_{pe,1m,30}$ = 77 dB $L_{pe,1m,31}$ = 75 dB $L_{pe,1m,32}$ = 72 dB $L_{pe,1m,33}$ = 70 dB
(25) A-weighted sound-pressure level 1 m from pipe wall $L_{pAe,1m} = 10 \cdot Log_{10}\left(\sum_{i=1}^{N=33} 10^{\frac{L_{pe,1m}(f_i) + \Delta L_A(f_i)}{10}}\right)$	$\Delta L_A(f_i)$ see 5.6.3 $\Rightarrow$ $L_{pAe,1m}$ = 89 dB(A)

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