

Industrial-process control valves —

Part 8: Noise considerations —

Section 3: Control valve aerodynamic noise prediction method

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ICS 17.140.20; 23.060.40

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- Energy Industries Council
- GAMBICA (BEAMA Ltd.)
- Health and Safety Executive
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- British Chemical Engineering Contractors Association
- British Pressure Gauge Manufacturers Association
- British Valve and Actuator Manufacturers' Association
- Department of Trade and Industry (National Engineering Laboratory)
- Department of Trade and Industry (Services Management Division)
- Engineering Industries Association
- Institution of Electrical Engineers
- Institute of Materials

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National foreword

This British Standard has been prepared by Technical Committee GEL/65 and is the English language version of EN 60534-8-3:1995 *Industrial-process control valves — Part 8: Noise considerations — Section 3: Control valve aerodynamic noise prediction method*, published by the European Committee for Electrotechnical Standardization (CENELEC). It is identical with IEC 534-8-3:1995 published by the International Electrotechnical Commission (IEC).

Cross-references

Publication referred to	Corresponding British Standard
	BS EN 60534 <i>Industrial-process control valves</i>
EN 60534-1:1993 (IEC 534-1:1987)	Part 1:1993 <i>Control valve terminology and general considerations</i> Part 2 <i>Flow capacity</i>
EN 60534-2-1:1993 (IEC 534-2-1:1978)	Section 1:1993 <i>Sizing equations for incompressible fluid flow under installed conditions</i>
EN 60534-2-2:1993 (IEC 534-2-2:1980)	Section 2:1993 <i>Sizing equations for compressible fluid flow under installed conditions</i>
EN 60534-2-3:1993 (IEC 534-2-3:1983)	Section 3:1993 <i>Test procedures</i>
IEC 534-8-1:1986	BS 5793 <i>Industrial-process control valves</i> Part 8 <i>Noise considerations</i> Section 8.1:1986 <i>Method for laboratory measurement of noise generated by aerodynamic flow through control valves</i>

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 44, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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Partie 8: Considérations sur le bruit
Section 3: Calcul du bruit généré par un débit
aérodynamique
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Stellventile für die Prozeßregelung
Teil 8: Geräuschemission
Hauptabschnitt 3: Berechnungsverfahren zur
Vorhersage der aerodynamischen Geräusche
von Stellventilen
(IEC 534-8-3:1995)

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European Committee for Electrotechnical Standardization
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Foreword

The text of document 65B/231/DIS, future edition 1 of IEC 534-8-3, prepared by SC 65B, Devices, of IEC TC 65, Industrial-process measurement and control, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60534-8-3 on 1995-09-20.

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- latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 1996-07-01
- latest date by which the national standards conflicting with the EN have to be withdrawn (dow) 1996-07-01

Annexes designated “normative” are part of the body of the standard. Annexes designated “informative” are given for information only. In this standard, Annex ZA is normative and Annex A and Annex B are informative. Annex ZA has been added by CENELEC.

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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 and 1 m from the pipe wall. This section offers a method to establish this value.

The equations in this section make use of the valve sizing factors as used in IEC 534-1, IEC 534-2, and IEC 534-2-2.

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.

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 (reference IEC 534-8-1).

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

NOTE Laboratory air tests conducted with up to 1 830 kPa (18,3 bar) upstream pressure and up to 1 600 kPa (16,0 bar) downstream pressure and steam tests up to 225 °C showed good agreement with the calculated values.

The transmission loss equations are based on a rigorous analysis of the interaction between the sound waves existing in the pipe and the many coincidence frequencies in the pipe wall. The wide tolerances in pipe wall thickness allowed in commercial pipe severely limit the value of the very complicated mathematical approach required for a rigorous analysis; therefore, a simplified method is used.

Example calculations are given in Annex A.

This method is based on the IEC standards listed in clause 2 and the references given in Annex B.

1 Scope and limitations

This section of International Standard IEC 534-8 establishes a theoretical method to predict the external sound-pressure level generated in a control valve 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 section addresses only the noise generated by aerodynamic processes in valves and in the connected piping. It does not consider any noise generated by reflections, mechanical vibrations, unstable flow patterns, and other unpredictable behaviour.

At this time, predictions are limited to a downstream maximum velocity in the valve outlet port of 0,3 Mach. Ideal straight pipe is assumed downstream.

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

For limitations on special low noise trims not covered by this section, see 6.5.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this section of IEC 534-8. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this section of IEC 534-8 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid normative documents.

IEC 534-1:1987, *Industrial-process control valves — Part 1: Control valve terminology and general considerations*.

IEC 534-2:1978, *Industrial-process control valves — Part 2: Flow capacity — Section 1: Sizing equations for incompressible fluid flow under installed conditions*.

IEC 534-2-2:1980, *Industrial-process control valves — Part 2: Flow capacity — Section 2: Sizing equations for compressible fluid flow under installed conditions*.

IEC 534-2-3:1983, *Industrial-process control valves — Part 2: Flow capacity — Section 3: Test procedures*.

IEC 534-8-1:1986, *Industrial-process control valves — Part 8: Noise considerations — Section 1: Laboratory measurement of noise generated by aerodynamic flow through control valves*.

3 Definitions

For the purpose of this International Standard, all of the definitions given in other parts of IEC 534 shall apply with the addition of the following:

3.1

acoustical efficiency

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

3.2

first coincidence frequency

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

3.3

fluted vane butterfly valve

a 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

3.4

independent flow passage

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

3.5

peak frequency

the frequency at which the internal sound pressure is a maximum

3.6

valve style modifier F_d

the 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_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 534-1)
C_n	Flow coefficient for last stage of multistage trim with n stages	Various (See IEC 534-1)
c_{vc}	Speed of sound in the <i>vena contracta</i> at subsonic flow conditions	m/s
c_{vcc}	Speed of sound in the <i>vena contracta</i> at critical flow conditions	m/s
c_2	Speed of sound at downstream conditions	m/s
D	Valve outlet diameter	m
d	Diameter of a flow passage (for other than circular, use d_H)	m
d_H	Hydraulic diameter of a single flow passage	m
D_i	Internal pipe diameter	m
D_j	Jet diameter at the <i>vena contracta</i>	m
d_o	Diameter of a circular orifice, the area of which equals the sum of areas of all flow passages at a given travel	m
F_d	Valve style modifier	Dimensionless
F_L	Liquid pressure recovery factor of a valve without attached fittings (see note 4)	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_o	First coincidence pipe frequency	Hz
f_p	Generated peak frequency	Hz
f_r	Ring frequency	Hz
l	Length of a radial flow passage	m
l_w	Wetted perimeter of a single flow passage	m
L_g	Correction for Mach number	$\text{dB (ref } P_o)$
L_{pAe}	A-weighted sound-pressure level external of pipe	$\text{dB(A) (ref } P_o)$
$L_{pAe,1\text{ m}}$	A-weighted sound-pressure level 1 m from pipe wall	$\text{dB(A) (ref } P_o)$
L_{pi}	Internal sound-pressure level at pipe wall	$\text{dB (ref } P_o)$
L_{wi}	Total internal sound power level	$\text{dB (ref } P_o)$
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_{vc}	Mach number at the <i>vena contracta</i>	Dimensionless
M_2	Mach number in downstream pipe	Dimensionless
$\dot{m}$	Mass flow rate	kg/s
$\dot{m}_s$	Mass flow rate at sonic velocity	kg/s

Symbol	Description	Unit
N	Numerical constants (see Table 1)	Various
N_0	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 last stage of multistage valve with n stages	Pa
P_o	Reference sound pressure = 2×10^{-5}	Pa
p_s	Standard atmospheric pressure (see note 1)	Pa
p_{vc}	Absolute <i>vena contracta</i> pressure at subsonic flow conditions	Pa
p_{vcc}	Absolute <i>vena contracta</i> pressure at critical flow conditions	Pa
p_1	Valve inlet absolute pressure	Pa
p_2	Valve outlet absolute pressure	Pa
p_{2B}	Valve outlet absolute pressure at break point	Pa
p_{2C}	Valve outlet absolute pressure at critical flow conditions	Pa
p_{2CE}	Valve outlet absolute pressure where region of constant acoustical efficiency begins	Pa
R	Universal gas constant = 8 314	J/kmol $\times$ K
T_n	Inlet absolute temperature at last stage of multistage valve with n stages	K
T_{vc}	<i>Vena contracta</i> absolute temperature at subsonic flow conditions	K
T_{vcc}	<i>Vena contracta</i> absolute temperature at critical flow conditions	K
T_1	Inlet absolute temperature	K
T_2	Outlet absolute temperature	K
TL	Transmission loss corrected for peak frequency	dB
TL_{fr}	Transmission loss at ring frequency	dB
ΔTL_{fr}	Differential between TL_{rf} and TL	dB
t_p	Pipe wall thickness	m
U_{vc}	<i>Vena contracta</i> velocity at subsonic flow conditions	m/s
W_a	Sound power	W
W_m	Stream power of mass flow	W
W_{ms}	Stream power of mass flow rate at sonic velocity	W
W_o	Reference sound power = 10^{-12}	W
α	Recovery correction factor	Dimensionless
γ	Specific heat ratio	Dimensionless
η	Acoustical efficiency factor (see note 2)	Dimensionless
ρ_1	Density of fluid at p_1 and T_1	kg/m ³
ρ_2	Density of fluid at p_2 and T_2	kg/m ³
ρ_n	Density of fluid at last stage of multistage valve with n stages at p_n and T_n	kg/m ³
Φ	Relative flow coefficient	Dimensionless

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 = 10^5 kPa = 10^5 Pa.

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

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.

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

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

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

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

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

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

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

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

$$p_{2c} = p_1 - F_L^2 (p_1 - p_{vcc}) \quad (3)$$

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

The correction factor α is the ratio of two pressure ratios: 1) the ratio of inlet pressure to outlet pressure at critical flow conditions and 2) the ratio of inlet pressure to *vena contracta* pressure at critical flow conditions. It is defined as follows:

$$\alpha = \frac{\left(\frac{p_1}{p_{2c}} \right)}{\left(\frac{p_1}{p_{vcc}} \right)} = \frac{p_{vcc}}{p_{2c}} \quad (4)$$

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

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

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

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

5.2 Regime definition

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

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

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

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

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

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

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

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

5.3 Preliminary calculations

5.3.1 Valve style modifier F_d

The valve style modifier may be calculated by:

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

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

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

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

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

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:

$$D_j = N_{14} F_d \sqrt{C F_L} \quad (8)$$

NOTE 1 N_{14} is a numerical constant, the values of which account for the specific flow coefficient (K_v or C_v) used. Values of the constants 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, replace F_L with F_{LP}/F_p .

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_{15}	$1,5 \times 10^{-5}$	$1,3 \times 10^{-5}$
N_{16}	$4,23 \times 10^4$	$4,89 \times 10^4$

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 ^a	0,29	0,40	0,42	0,43	0,45	0,48
Globe, 4 V-port plug	Either ^a	0,25	0,35	0,36	0,37	0,39	0,41
Globe, 6 V-port plug	Either ^a	0,17	0,23	0,24	0,26	0,28	0,30
Globe, 60 equal diameter hole drilled cage	Either ^a	0,40	0,29	0,20	0,17	0,14	0,13
Globe, 120 equal diameter hole drilled cage	Either ^a	0,29	0,20	0,14	0,12	0,10	0,09
Butterfly, swing-through (centered shaft), to 70°	Either	0,26	0,34	0,42	0,50	0,53	0,57
Butterfly, fluted vane, to 70°	Either	0,08	0,10	0,15	0,20	0,24	0,30
60° flat disk	Either						0,50
Eccentric rotary plug	Either	0,12	0,18	0,22	0,30	0,36	0,42
Segmented ball	Either	0,60	0,65	0,70	0,75	0,78	0,80
NOTE These values are typical only; actual values shall be stated by manufacturer.							
^a Limited $p_1 - p_2$ in flow to close direction.							

5.4 Regime I (subsonic flow)

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

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

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

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

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

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

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

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

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

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

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

$$\eta_1 = (1 \times 10^{-4}) M_{vc}^{3,6} \quad (14)$$

Thus, the sound power generated in regime I is:

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

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

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

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

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

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

$$f_p = \frac{0,2 U_{vc}}{D_j} \quad (17)$$

5.5 Regimes II to V (common calculations)

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

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

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

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

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

Stream power is then calculated as follows:

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

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

In the *vena contracta*, the Mach number is calculated from the following equation for regimes II through IV:

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

5.5.1 Regime II

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

$$\eta_2 = (1 \times 10^{-4}) M_j^{6,6} F_L^2 \quad (22)$$

NOTE When the valve has attached fittings, replace F_L with F_{LP}/F_p .
The sound power generated may be calculated as follows:

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

The peak frequency is then determined as follows:

$$f_p = \frac{0,2 M_j c_{vcc}}{D_j} \quad (24)$$

5.5.2 Regime III

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

$$\eta_3 = (1 \times 10^{-4}) M_j^{6,6} F_L^2 \quad (25)$$

NOTE When the valve has attached fittings, replace F_L with F_{LP}/F_p .
The sound power is given by the following equation:

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

The peak frequency is calculated from equation (24).

5.5.3 Regime IV

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

$$\eta_4 = (1 \times 10^{-4}) \left(\frac{M_j^2}{2} \right) (\sqrt{2})^{6,6} F_L^2 \quad (27)$$

NOTE When the valve has attached fittings, replace F_L with F_{LP}/F_p .
Sound power is then calculated from the following equation:

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

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

$$f_p = \frac{0,35 c_{vcc}}{1,25 D_j \sqrt{M_j^2 - 1}} \quad (29)$$