

Evaluating the calculation accuracy provided by the relevant noise prediction standards for control valves



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Noise emission to be expected from control and shut-off valves is an important criterion on planning industrial plants. Its importance is highlighted by legislation requirements regarding occupational health and safety as well as environmental protection. Various calculation standards (VDMA 24422: 1979, VDMA 24422: 1989, IEC 60534-8-3: 2001 and IEC 60534-

8-4: 1994) presently exist to determine noise emission that mainly differ depending on the flow medium. The following article evaluates these standards by comparing their accuracy to the large number of measurements carried out by SAMSON.

Übersicht über die Genauigkeit von Schallberechnungsnormen bei Stellgeräten

Bei der Projektierung von Industrieanlagen ist die zu erwartende Geräuschemission von Regel- und Absperrarmaturen ein wichtiger Planungsparameter, dessen Bedeutung durch die Arbeits- und Umweltschutzgesetzgebung bedingt ist. Für die Ermittlung der Geräuschemission gibt es heute im Wesentlichen je nach Durchflussmedium verschiedene Berechnungsnormen

(VDMA 24422:1979, VDMA 24422: 1989, IEC 60534-8-3: 2001 und IEC 60534-8-4: 1994), die in dem folgenden Beitrag unter dem Gesichtspunkt der Genauigkeit mit einer großen Anzahl von vorhandenen Messergebnissen der Firma SAMSON verglichen und bewertet werden.

1. Introduction

Noise prediction methods make a distinction between compressible and non-compressible flow media. The reason for this is that compressible and non-compressible flow media have different sound characteristics:

In gases and vapors, the profile of the sound pressure level increases continuously with increasing differential pressure ratio at low outlet Mach numbers ($Ma < 0.3$). The noise emission profile of liquids, however, increases almost constantly only in the turbulent flow region and then rises parabolically in the cavitation region as can be seen in Figure 1.

The noise prediction standards evaluated in this paper can be classified according to the type of medium as follows:

Noise prediction standards providing calculation formulae for liquids [5, 6]

- VDMA 24422 (1979) [1]
- IEC 60534-8-4 (1994)[3] (almost identical with VDMA 24422 (1989) [2])

Noise prediction standards providing calculation formulae for gases and vapors

- VDMA 24422 (1979) [1]
- VDMA 24422 (1989) [2]
- IEC 60534-8-3 (2001) [3]

These standards do not only differ in their approaches to predict noise emission, but also in their quantitative scope. The VDMA 24422 (1979) noise prediction method only allows for the calculation of the sound pressure level at a distance of one meter from the control valve, whereas the other methods can additionally be used to calculate the internal sound power level as well as the frequency-dependent noise emission values (see Table 1).

2. Comparing numerical predictions with experimental data

The noise prediction standards were evaluated by comparing the results of the internal and external sound pressure levels calculated according to the noise prediction methods of the standards with the measuring results provided by SAMSON AG. In order to obtain these measuring results, SAMSON AG

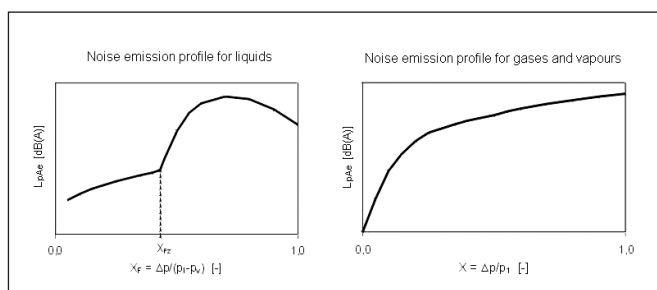


Fig. 1: Typical noise emission profiles for liquids and gases/vapors



Fig. 2: Test bench at SAMSON AG

has been undertaking measurements on its test benches (see Figure 2) for many years.

The measurements of the internal sound pressure level were taken according to the test procedure described in VDMA 24423 [4] and the measurements of the external sound pressure level were performed to meet the testing requirements of IEC 60534-8 Parts 1 and 2. The measurements were carried out on control valves featuring the following design:

- Globe valves with parabolic plugs or V-port plugs
- Globe valves with one-stage perforated plugs
- Rotary plug valves
- Butterfly valves
- Segmented ball valves
- All valves without any special noise attenuation
- K_{vs} values ranging from 0.4 to 700
- Nominal sizes ranging from DN 25 to DN 200

To satisfy the requirements of the relevant standards, separate measurements were performed for compressible and non-compressible media, using air and water as test media.

Characteristics of the noise emission measurements using:

Air:

- Maximum Mach number at the valve outlet: $Ma \leq 0.3$
- Differential pressure ratio ranging from 0.2 to 0.85
- About 2500 measuring points

Water:

- Use of the measured x_{Fz} value
- Differentiation between turbulent and cavitation regions
- About 5000 measuring points

The evaluation of the calculation accuracy provided by the

noise prediction standards is based on the mathematical differences between the calculated and the measured values for both the external and the internal sound pressure levels:

- $L_{pAe,Standard} - L_{pAe,Measurement}$
- $L_{pi,Standard} - L_{pi,Measurement}$

3. Accuracy of the noise prediction standards

The analysis of the mathematical differences between the calculated and the measured values for the sound pressure levels basically reveals that VDMA 24422 (1979) provides the most accurate prediction of the external sound pressure level, irrespective of the medium, valve type (with the exception of valves equipped with special low-noise accessories such as flow di-

viders) or nominal size of the control valve. The noise prediction standard VDMA 24422 (1989) could be considerably improved if its freely adaptable factors G_1 , G_2 or F_1 , F_2 , Δ_L were derived from measurements carried out on control valves, using standard media, i.e. air or water (see Figures 3 and 4, for example). The international standards IEC 60534-8-3 (2001) and IEC 60534-8-4 (1994) do not allow for this adaptation because they assume that noise prediction standards should rather do without any additional measurements or adaptations and should be a compromise between the degree of accuracy and the amount of work and time spent to perform the measurements and predictions. Of course, such a reduction of accuracy cannot be in the users' interest.

Table 1: Overview of the noise prediction standards and their parameters

Parameter/ Factor	Standards for compressible media				Standards for non-compressible media		
	VDMA 24422 (1979)	VDMA 24422 (1989)	VDMA 24422 (1989) adapted	IEC 60534-8-3 (2001)	VDMA 24422 (1979)	IEC 60534-8-4 (1994)/ VDMA 24422 (1989)	IEC 65B-WG9 (current draft)
F_L				x		x	x
x_T		x	x				
F_d				x			x
x_{Fz}					x	x	x
K_v	x			x	x		x
D	x			x	x		x
d_0				x			x
d_i, s	s only	x	x	x	s only	x	x
F_1, F_2						Adaptable acc. to VDMA standard/ fixed acc. to IEC standard: $F_1=-8, F_2=0$	
Δ_L					x	Adaptable acc. to VDMA standard/ fixed acc. to IEC standard: $L_f=0$	
G_1, G_2		Fixed: $G_1=-3, G_2=0.8$	Adaptable				
Δ_{LG}	x						
p_1, p_2	x	x	x	x	x	x	x
W		x	x	x		x	x
T_1	x			x			
p_1	x	x	x	x	x	x	x
p_v					x	x	x
κ		x	x	x			
L_{pi} or L_{Wi}		x	x	x		x	x
L_{We}		x	x			x	x
L_{pAe}	x	x	x	x	x	x	x
Frequency information		Octaves	Octaves	Peak frequency		Octaves	Octaves, thirds, peak frequency

3.1. Compressible media

This section presents the results obtained for the internal and external sound pressure levels for compressible media, evaluating them in detail in terms of their accuracy (see Figures 3 and 4 and Table 2).

- VDMA 24422 (1979) predicted 33% of the measured external sound pressure levels L_{pAe} within a deviation range of ± 2.5 dB(A) and as much as approximately 60% within a deviation range of ± 5 dB(A) as can be seen in Figure 3 and Table 2.
- Both VDMA 24422 (1989) and IEC 60534-8-3 (2001) significantly overpredicted the measured external sound pressure levels L_{pAe} . The mean deviation error was 10 dB(A) under the VDMA 24422 (1989) calculation scheme and about 7 dB(A) when using IEC 60534-8-3 (2001).
- Like the external sound pressure levels L_{pAe} , the internal sound pressure levels L_{pi} were considerably overpredicted by VDMA 24422 (1989) and mostly deviated from the numerical predictions in the deviation range (deviation error = $L_{pi,Standard} - L_{pi,Measurement}$) from +7.5 to +12.5 dB as illustrated in Figure 4.
- Comparing the external sound pressure levels with the internal sound pressure levels calculated according to IEC 60534-8-3 (2001), however, revealed opposite trends: the external sound pressure levels L_{pAe} were overpredicted (by 7 dB(A) as mentioned before) whereas many of the internal sound pressure levels L_{pi} were underpredicted by IEC 60534-8-3 (2001). About 40% of the calculated values deviated by -7.5 to -2.5 dB from the measured levels.
- The examination of the sound pressure levels calculated for compressible media according to the three relevant standards revealed that, irrespective of the standard used, 90% of all calculated deviations from the measured values covered an overall deviation range of 20 dB.
- The results discussed in this section were similar for different nominal sizes and for both the overall examination of different valve types and the individual examination of only one valve type.

VDMA 24422 (1989) mainly overpredicted both the external and the internal sound pressure levels because it had calculated too large a value for the acoustical conversion ratio η_G , whereas IEC 60534-8-3 (2001) had calculated too small a value for the acoustical conversion ratio and therefore underpredicted the internal sound pressure levels for most valve types. The external sound pressure levels were overpredicted under the IEC 60534-8-3 (2001) prediction method because of the inexact determination of the peak frequency, on the one hand, and because of the calculation of too low a value for the pipe transmission loss T_L for certain frequency ranges, on the

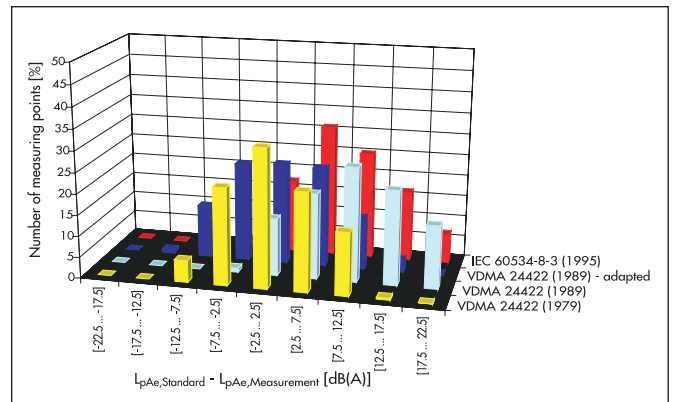


Fig. 3: External sound pressure level - Air

Error distribution determined for the external sound pressure level of air as a representative of compressible media (total number of measuring points: $N = 2386$, nominal size: $50 \leq DN \leq 200$, differential pressure ratio: $0.2 < x < 0.85$)

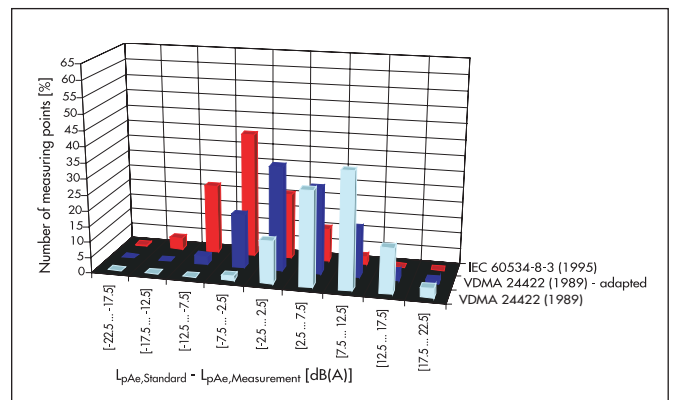


Fig. 4: Internal sound pressure level - Air

Error distribution determined for the internal sound pressure level of air as a representative of compressible media (total number of measuring points: $N = 2386$, nominal size: $50 \leq DN \leq 200$, differential pressure ratio: $0.2 < x < 0.85$)

other hand (see Figure 5). The external sound pressure levels, however, can be calculated to a considerably higher degree of accuracy under the IEC 60534-8-3 (2001) prediction method provided that the valve style modifier F_d is determined on the basis of previous measurements. Neglecting the lower sound pressure levels ($L_{pAe} \leq 75$ dB(A)), a higher degree of accuracy is obtained in the tolerance range of ± 5 dB(A): if the sound pressure levels are calculated using a corrected, i.e. reduced valve style modifier, the degree of accuracy is increased from 53% (when the uncorrected valve style modifier is used) to 67% (when the valve style modifier is corrected as follows: $F_d = 0.5 \cdot F_{d,IEC}$, see Figure 6). It is important to note that unlike the external sound pressure levels, the internal sound pressure levels are not predicted on the basis of the valve style modifier and therefore cannot be corrected.

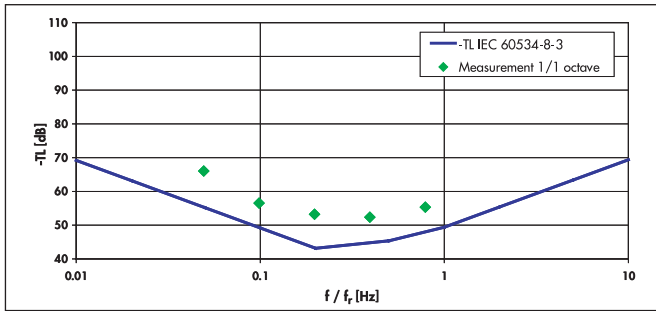


Fig. 5: Deviation of the sound transmission loss values calculated under IEC 60534-8-3 from those determined on the test bench (for DN 80)

3.2. Non-compressible media

When calculating the noise emission of non-compressible media, it is important to precisely determine the beginning of cavitation expressed by the x_{Fz} value because a deviation from the actual x_{Fz} value by ± 0.05 leads to a considerable overprediction or underprediction of the actual sound pressure level in the order of up to 25 dB.

The reason for this is that noise emission begins to rise sharply at the point when cavitation occurs, as can be seen in Figure 1. It was found that the evaluation of the noise prediction standards for non-compressible media provided almost the same results as the analysis of the noise prediction standards for compressible media (see Figures 7 to 10 and Table 3).

- Both VDMA 24422 (1979) and IEC 60534-8-4 (1994) underpredicted the noise emitted by control valves in the turbulent flow region. From Figure 7, it is evident that most of the predicted external sound pressure levels were about 7.5 to 2.5 dB lower than the measured values, i.e. 37% of the calculated results obtained under the VDMA 24422 (1979) prediction method and 32% of the predictions under the IEC 60534-8-4 (1994) standard came within the deviation range from -7.5 to -2.5 dB. An accuracy of -7.5 to 2.5 dB was obtained for more than 60% of the values calculated according to VDMA 24422 (1979) and for less than 50% of the values calculated according to IEC 60534-8-4 (1994).

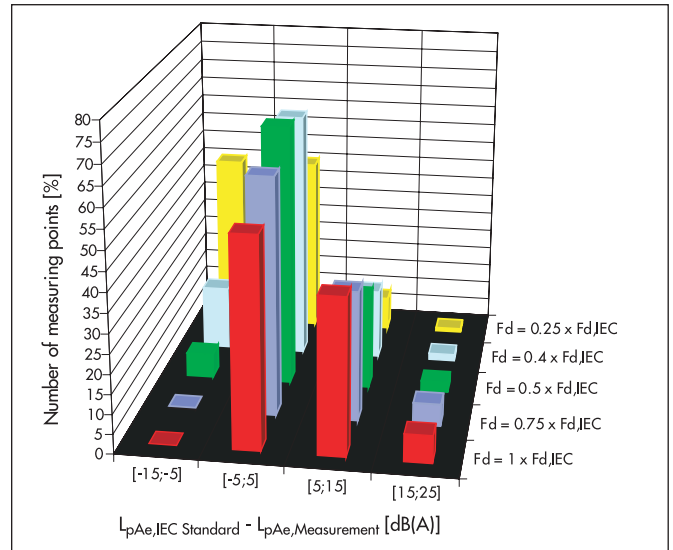


Fig. 6: IEC 60534-8-3 (2001) · F_d factor variation · External sound pressure level · Air

Error distribution with F_d factor variation for the standard IEC 60534-8-3 (2001) determined for the external sound pressure level of air as a representative of compressible media (total number of measuring points: $N = 1565$, nominal size: $50 \leq DN \leq 200$; differential pressure ratio: $0.2 < x < 0.85$; external sound pressure level $L_{pAe} > 75$ dB(A))

- Like the external sound pressure levels occurring in the turbulent region, the internal sound pressure levels were underpredicted by IEC 60534-8-4 (1994). Compared with the majority of the external sound pressure levels, which were accurate to within -12.5 to -2.5 dB, the majority of the internal sound pressure levels were even 5 dB lower, i.e. as much as approximately 65% of all measuring points were predicted to within -17.5 to -7.5 dB as can be seen in Figure 8.
- The external sound pressure levels predicted according to VDMA 24422 (1979) for the cavitation region featured an error distribution which was similar to that of the levels calculated for the turbulent region. The levels predicted for the cavitation region, however, showed a higher degree of accuracy because as much as approximately 70% of the predictions were within the -7.5 to 2.5 dB deviation range as illustrated in Figure 9.

Table 2: Overview of the accuracy provided by the noise prediction standards for compressible media. The accuracy is expressed as a percentage of all calculated values lying in a particular accuracy or deviation range, such as ± 2.5 dB(A), ± 5 dB(A) or ± 7.5 dB(A)

Standard	A-weighted external sound pressure level L_{pAe}			Internal sound pressure level L_{pi}		
	± 2.5 dB(A)	± 5 dB(A)	± 7.5 dB(A)	± 2.5 dB	± 5 dB	± 7.5 dB
VDMA 24422 (1979)	About 35%	About 60%	About 80%			
VDMA 24422 (1989)	About 15%	About 20%	About 35%	About 15%	About 30%	About 45%
VDMA 24422 (1989) adapted	About 25%	About 50%	About 70%	About 35%	About 60%	About 80%
IEC 60534-8-3 (2001)	About 20%	About 30%	About 50%	About 20%	About 45%	About 70%

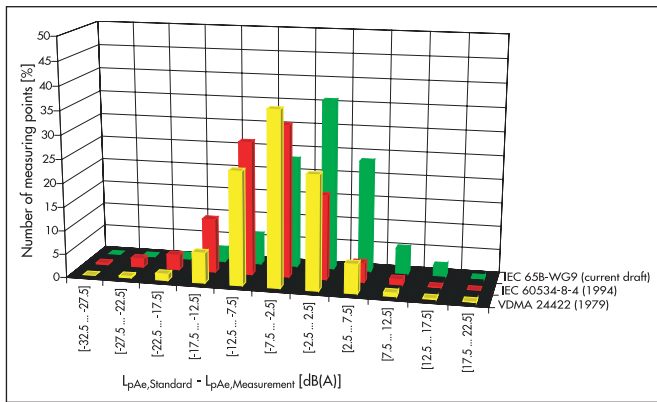


Fig. 7: External sound pressure level · Water · Turbulent region
 Error distribution in the turbulent region determined for the external sound pressure level of water as a representative of non-compressible media (total number of measuring points: N = 1698, nominal size: 25 ≤ DN ≤ 200)

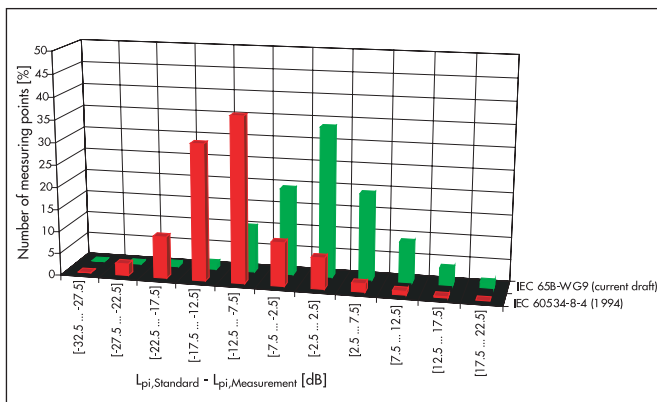


Fig. 8: Internal sound pressure level · Water · Turbulent region
 Error distribution in the turbulent region determined for the internal sound pressure level of water as a representative of non-compressible media (total number of measuring points: N = 1698, nominal size: 25 ≤ DN ≤ 200)

- In comparison with the external sound pressure levels obtained for the turbulent region, the results calculated for the cavitation region according to IEC 60534-8-4 (1994) were even less accurate: about 70% of all predictions deviated from the measured values by -17.5 to -7.5 dB.

- It was found that the IEC 60534-8-4 (1994) predictions for the internal and the external sound pressure levels in the cavitation region showed similar levels of accuracy.
- Like the analysis of the sound pressure levels predicted for compressible media, the examination of the sound pressure levels calculated for non-compressible media according to the two relevant standards revealed that, irrespective of the standard used, 90% of all calculated deviations from the measured values covered an overall deviation range of 20 dB.
- The results discussed in this section were similar for different nominal sizes and for both the overall examination of different valve types and the individual examination of only one valve type.

IEC 60534-8-4 (1994) underpredicted both the internal and the external sound pressure levels because it had determined too low a value for the acoustical conversion ratio η_F . Predictions for the noise emission of liquids performed according to VDMA 24422 (1979) are reasonably accurate provided that the x_{Fz} value has been determined by means of measurements.

4. Summary and outlook

It was found that VDMA 24422 (1979) predicted the noise emission to a relatively high degree of accuracy irrespective of the type of medium. As indicated in the VDMA 24422 (1979) standard, predictions deviated from the measurements by just ± 5 dB(A), proving the specified degree of calculation accuracy to be correct. Using the specific valve correction values for liquids and gases, i.e. ΔL_F and ΔL_G respectively, allows the sound pressure levels of special low-noise valve designs to be adapted to measurements. A disadvantage is that VDMA 24422 (1979) only predicts the external sound pressure level. Compared with VDMA 24422 (1979), the other standards provide far less accurate predictions which deviate considerably from the measured values. These findings largely confirm the validation results obtained by IEC for the IEC 60534-8-3 (2001) standard. The degree of accuracy, however, can be increased considerably provided that the valve style modifier F_d is determined on the basis of previous measurements.

Table 3: Overview of the accuracy provided by the noise prediction standards for non-compressible media. The accuracy is expressed as a percentage of the calculated values and indicated for different deviation ranges, such as ± 2.5 dB(A), ± 5 dB(A) or ± 7.5 dB(A)

Standard	A-weighted external sound pressure level L_{pAe}			Internal sound pressure level L_{pi}		
	± 2.5 dB(A)	± 5 dB(A)	± 7.5 dB(A)	± 2.5 dB	± 5 dB	± 7.5 dB
VDMA 24422 (1979)	About 30%	About 60%	About 80%			
IEC 60534-8-4 (1994)	About 10%	About 20%	About 30%	About 5%	About 10%	About 20%
IEC 65B-WG9 (current draft)	About 40%	About 65%	About 85%	About 35%	About 60%	About 80%

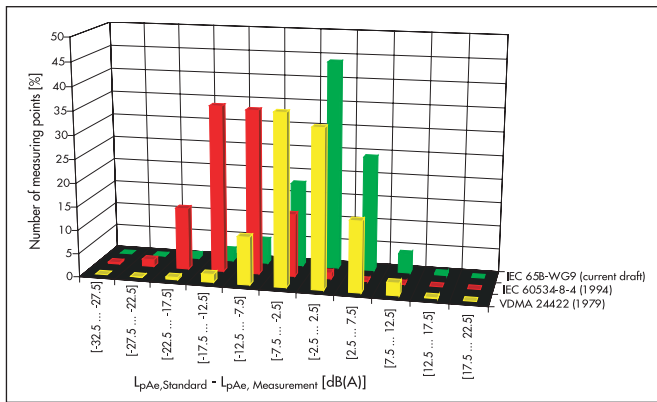


Fig. 9: External sound pressure level · Water · Cavitation region
 Error distribution in the cavitation region determined for the external sound pressure level of water as a representative of non-compressible media (total number of measuring points: N = 3027, nominal size: 25 ≤ DN ≤ 200)

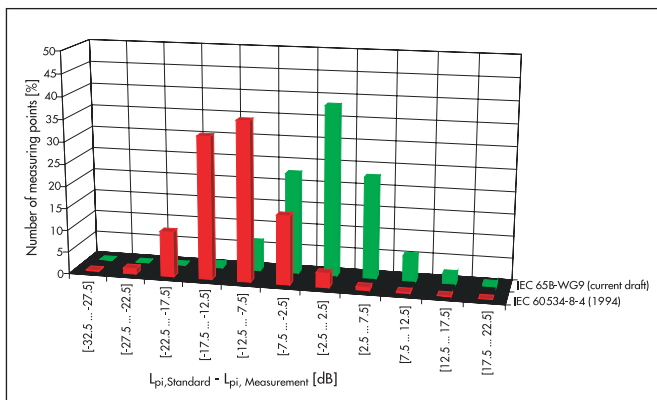


Fig. 10: Internal sound pressure level · Water · Cavitation region
 Error distribution in the cavitation region determined for the internal sound pressure level of water as a representative of non-compressible media (total number of measuring points: N = 3027, nominal size: 25 ≤ DN ≤ 200)

It is important to note that, unlike the external sound pressure levels, the internal sound pressure levels are not predicted by means of the valve style modifier and therefore cannot be optimised in this way. The advantage provided by VDMA 24422 (1989), however, is that it allows the calculation factors G_1 , G_2 or F_1 , F_2 , ΔL_F to be adapted to the measuring results by calculating them on the basis of measurements. If these factors are determined mathematically, the sound pressure level can be predicted to a much higher degree of accuracy than by using the standard factor values (the results provided by VDMA 24422 (1989) are almost as precise as those obtained under VDMA 24422 (1979) as can be seen in Table 2). VDMA 24422 (1989) has considerable advantages over VDMA 24422 (1979) because it additionally allows the internal sound pressure level as well as the frequency-dependent noise emission to be calculated. These data are important to acous-

tics experts operating in the field of industrial plant design and to manufacturers of throttle silencers to be installed downstream of a control valve in applications involving, for example, the release of the process medium into the atmosphere. Moreover, this standard allows the noise emitted by control valves featuring a low-noise design to be predicted using values derived mathematically from measurements for the freely adaptable factors G_1 and G_2 . Furthermore, the formula for the pipe sound transmission loss takes into account the corresponding nominal size. This adapted version of VDMA 24422 (1989) has been used successfully by SAMSON for many years. The IEC 60534-8-4 (1994) standard for non-compressible media is currently under review. SAMSON's measuring results used for the validation of the reviewed version are illustrated in Figures 7 to 10 and in Table 3. From these figures, it is evident that the reviewed version will predict both the internal and the external sound pressure levels much more accurately and even more precisely than VDMA 24422 (1979). Nevertheless, this reviewed version will still have to be continuously improved and validated by other manufacturers.



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Terms and units

Term	Unit	Definition
η_F	-	Acoustical conversion ratio for liquids
η_G	-	Acoustical conversion ratio for gases
κ	-	Specific heat ratio
ρ	-	Density of fluid
D	m	Nominal size of valve
d_i	m	Internal pipe diameter
d_0	m	Diameter of a circular orifice
F_d	-	Valve style modifier
F_L	-	Liquid pressure recovery factor of a valve
F_1	-	Level exponent in the equation for h_F
F_2	-	Slope exponent in the equation for h_F
f_r	Hz	Ring frequency of the pipe
f_p	Hz	Peak frequency acc. to IEC 534-8-3 (2001)
G_1	-	Level exponent in the equation for h_G
G_2	-	Slope exponent in the equation for h_G
K_v	m ³ /h	Flow coefficient of a valve
K_{vs}	m ³ /h	Flow coefficient of a valve at rated travel
Ma	-	Mach number
ΔL_F	dB(A)	Specific valve correction value for liquids
ΔL_G	dB(A)	Specific valve correction value for gases and vapors
L_{pAe}	dB(A)	A-weighted external sound pressure level
L_{We}	dB(A)	External sound power level
L_{pi}	dB	Internal sound pressure level
L_{Wi}	dB	Internal sound power level
p_v	bar	Absolute vapor pressure of liquid
p_1	bar	Absolute upstream pressure
p_2	bar	Absolute downstream pressure
s	m	Thickness of pipe wall
T	K	Temperature of the fluid
T_L	dB	Sound transmission loss corrected for peak frequency
W	kg/h	Mass flow of the fluid
x	-	Differential pressure ratio for gases and vapors
x_F	-	Differential pressure ratio for liquids
x_{Fz}	-	Differential pressure ratio at beginning of cavitation
x_T	-	Differential pressure ratio at choked flow

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