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Improvements in the Determination of the Emission Sound Pressure Level of Machines

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Table of contents

Improvements in the Determination of the Emission Sound Pressure Level of Machines

Abstract

According to the machine directive, it is necessary to determine and declare the emission sound pressure levels of machines that are offered on the market. Depending on the value, it may also be necessary to declare the sound power level.

The emission sound pressure level can be determined using one of the standards of the ISO 11200 series.

Unfortunately, the practical application and use of these standards has led to a number of problems. Measurement according to ISO 11201 may lead to less accurate results than they should be expected from the assigned grade of accuracy. The same applies to ISO 11202 – there are many configurations where uncontrollably large errors occur. The existing version of ISO 11204 is often not applicable. Many users claim that this procedure is too time-consuming and ineffective, because the levels must be measured on an enveloping surface.

It was the aim of this investigation to improve the standards and to integrate the experience of the last few years. Investigating the dependency between environmental correction and the technical parameters describing the measurement setup, many improvements are recommended to reduce the uncertainties or – with given uncertainty – to reduce the time effort necessary for this measurement.
The following structure for the revised series of standards is proposed:

ISO 11201 – An environmental correction is not applied
Part 1 reference method grade 1 in rooms with free field conditions according to ISO 3745
Part 2 reference method grade 1 for measurements outside
Part 3 method grade 2 or 3 to be used in any room that meets defined requirements (this part is in discussion).

ISO 11202 – Application of an environmental correction determined with approximate methods
Part 1 for very small machines or any machines with a small identifiable surface area where the main noise emission occurs
Part 2 for machines of any size and shape with the approximate determination of the directivity. In both cases, the results can be qualified as grade 2 or 3.

ISO 11204 – Application of an environmental correction, that takes into account room characteristics and directivity of the emission.
The applicability is improved related to ISO 112001:1996 by introducing a two step procedure in the determination of the environmental correction. This report contains also same basic research and describes strategies to reduce the measurement expenditure by using existing knowledge about the source distribution and radiation.

Key words:

Emission Sound Power Level, Measuring Procedure, ISO 11200

Verbesserungen bei der Ermittlung des Emissions-Schalldruckpegels von Maschinen

Kurzreferat

Nach Maschinenrichtlinie ist für alle auf dem Markt angebotenen Maschinen u.a. der Emissions-Schalldruckpegel zu bestimmen und anzugeben. Der ermittelte Wert ist dann das Kriterium dafür, ob auch noch zusätzlich der Schallleistungspegel angegeben werden muss.

Diese Bestimmung des Emissions-Schalldruckpegels erfolgt nach einer der Normen der Reihe ISO 11200. Allerdings hat sich in der bisherigen Praxis gezeigt, dass die Anwendung dieser Normen zu erheblichen Problemen führt. Die Messung nach ISO 11201 kann zu ungenaueren Ergebnissen führen, als dies aufgrund der zugeordneten Genauigkeitsklasse erwartet werden sollte. Auch die ISO 11202, die ebenfalls mit Messungen ausschließlich am Arbeitsplatz auskommt, ergibt bei vielen mit der Norm verträglichen Bedingungen unkontrollierbar große Fehler.

Im Rahmen des diesem Bericht zugrundeliegenden Projekts wurde die Abhängigkeit des Emissions-Schalldruckpegels von den der Messung zugänglichen Parametern grundlegend untersucht. Das Ziel ist es, die Normen zur Bestimmung dieses Kennwerts so zu ändern bzw. zu ergänzen, dass der Messaufwand möglichst gering gehalten werden kann. Folgende Struktur der überarbeiteten Normenreihe wird vorgeschlagen:

ISO 11201 – keine Anwendung einer Umgebungskorrektur
Teil 1 als Referenzmethode Genauigkeitsklasse 1 in Räumen gemäß ISO 3745
Teil 2 als Referenzmethode Genauigkeitsklasse 1 für Messung im Freien
Teil 3 als Methode nach Genauigkeitsklasse 2 und 3 für die Messung in beliebigen Räumen

ISO 11202 – Anwendung einer nach vereinfachten Verfahren ermittelten Umgebungskorrektur
Teil 1 für sehr kleine Maschinen sowie für Maschinen mit der wesentlichen Geräuschemission durch einen räumlich begrenzten lokalisierbaren Schallquellenbereich. Teil 2 für beliebige Maschinen mit der Einbeziehung einer vereinfacht ermittelten Richtwirkung. In beiden Fällen bestehen eindeutige Kriterien zur Zuordnung der Ergebnisse zur Genauigkeitsklasse 2 oder 3.

ISO 11204 – Anwendung einer Umgebungskorrektur, die die Gesamtabstrahlung der Maschine einbezieht. Die Anwendbarkeit wird durch Einführung eines zweistufigen Verfahrens bei der Bestimmung der Umgebungskorrektur gegenüber ISO 11204: 1996 wesentlich verbessert.

Dieser Bericht umfasst auch grundlegende Untersuchungen und zeigt Möglichkeiten der Reduzierung des Messaufwands auf der Basis von Vorwissen über die Maschinenabstrahlung auf.

Schlagwörter:
Emissions-Schalldruckpegel, Messverfahren, ISO 11200

Améliorations dans la mesure du niveau de pression acoustique de l'émission sonore de machines

Résumé

Conformément à la directive « Machines », toutes machines proposées à la vente doivent donner lieu à mesure et à indication du niveau de pression acoustique de l’émission sonore. La valeur obtenue pour ce paramètre détermine ensuite l’obligation d’indiquer le niveau de puissance sonore ou non.

Ce niveau de pression acoustique d’émission sonore est déterminé selon l’une des normes de la série ISO 11200. Mais, on a constaté dans la pratique que l’application de ces normes entraînait des problèmes considérables. La mesure selon ISO 11201 peut causer des résultats moins précis que ce que l’on serait en droit d’attendre si l’on se basait sur la classe de précision spécifiée. La norme ISO 11202, qui ne stipule également que des mesures au poste de travail, entraîne des erreurs incontrôlable dans de nombreuses conditions compatibles avec la norme.

Dans le cadre du projet sur lequel le rapport présent est basé, on a étudié le dépendance fondamental existant entre le niveau de pression acoustique d’émission sonore et les paramètres accessibles à la mesure. L’objectif est de modifier les normes de mesure de cet indice et de les compléter de façon que le travail de mesure reste aussi limité que possible. Il est proposé que la série révisée des normes concernées ait la structure suivante:

ISO 11201 – pas d’application d’une correction environnementale
Partie 1 méthode de référence classe de précision 1 dans des locaux selon ISO 3745 Partie 2 méthode de référence classe de précision 1 pour mesure à l’extérieur de bâtiments. Partie 3 méthode selon les classes de précision 2 et 3 pour la mesure dans des locaux quelconques

ISO 11202 – application d’une correction environnementale déterminée selon des procédés simples. Partie 1 pour très petites machines ainsi que pour des machines dont l’émission sonore essentielle passe par une zone de source de bruit localisable et limitée dans l’espace. Partie 2 pour des machines quelconques prenant en compte la directivité d’une manière simple. Dans les deux cas, ils existent des critères clairs d’affectation des résultats à la classe de précision 2 ou à la classe de précision 3.

ISO 11204 – application d’une correction environnementale prenant en compte le rayonnement total émis par la machine. L’applicabilité est très améliorée par rapport à ISO 11204:1996, grâce à l’adoption d’un procédé en deux phases de détermination de la correction environnementale.

Ce rapport comprend aussi des analyses de fond et specifie des possibilités de réduction du travail de mesure sur la base de connaissances antérieures sur le rayonnement émis par une machine.

Mots clés:
Niveau de pression acoustique émise, procédés de mesure, ISO 11200

1 Introduction

The sound power level L_W and the emission sound pressure level L_p are the most important sound-related parameters for the description of the noise emission of a machine.

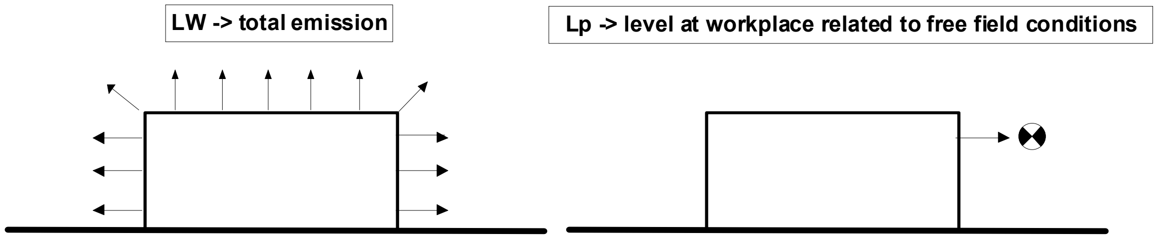

Fig. 1.1 The two parameters sound power level L_W und emission sound pressure level L_p

This has also been taken into account in the legally regulated area. Due to the Machine Directive /1/ and/or the 3rd and 9th ordinance for the (German) Device Safety Act /2, 3/ as their national implementation, the manufacturers of machines are obliged to specify the sound power level L_W of the products they sell in the EU market if their emission sound pressure level exceeds 85 dB(A). If this is not the case, the emission sound pressure level is to be specified in all cases where it exceeds 70 dB(A).

This makes the emission sound pressure level the most important parameter to be determined in each case. Only when its value is known can the decision be made as to whether the sound power level has to be determined also.

Unfortunately, however, determining this emission sound pressure level by measurement *in situ* – i.e. at the usual place of installation in the production facility – usually involves a number of problems. Reflections from the room boundary surfaces and from other machines and fixtures increase the sound pressure level at the workplace, and these have to be taken into account by subtracting a correction K_3 related to this workplace position. And this correction is the problem. Whereas the environmental correction K_2 for correction of the mean sound pressure level related to a greater measurement surface area is relatively insensitive to local deviations of the room sound field from the theoretically calculated value in determining the sound power level due to this spatial averaging, deviations of this kind in the correction for an individual point have a direct effect on the result as errors.

Another problem is that the sound pressure level of the room sound field produced by the machine itself - and thus also the stated environmental correction K_3 - depends on the total emission of the machine and thus on its sound power level L_W. This results – expressed in a slightly exaggerated manner – in the following situation:

According to the machines directive, it depends on the emission sound pressure level of a machine whether the sound power level has to be declared and therefore additionally be determined. The measurement of this emission sound pressure level, however, requires an environmental correction, which in turn requires determination of the sound power level, at least indirectly.

The necessity for a measurement of the total emission of the machine only in order to obtain the environmental correction K_3 for determining the emission sound pressure level has always been a problem for acceptance of the standard ISO 11204 /7/ that regulates this method. A European project for measurement of the emission sound pressure level /9/ has also shown that this method requires considerable effort when applied in the usual industrial environment.

It is a wish on the part of all those concerned that it should be sufficient for determining the emission sound pressure level to measure the sound pressure level directly and exclusively at the workplace and the environmental correction K_3 including the acoustic spatial and/or environmental properties.

To take this into account, approximate and less time consuming methods have been established with ISO 11201 /4/ and ISO 11202 /5/.

ISO 11201 neglects the environmental correction and the direct measured value of the averaged sound pressure level is used as the emission sound pressure level directly. In specifying that this is only permitted for rooms in which the correction K_2 in relation to the entire measurement surface area is less than 2 dB, the intention was to make the uncertainty related to this neglect compatible with grade 2.

ISO 11202 calculates the environmental correction under the condition that the position of the determining sound source is known. The emission sound pressure level determined in this way is assigned grade 3.

The other methods according to ISO 11203 /6/ (L_p is calculated by subtracting a constant Q to be set for each specific machine from the sound power level determined by measurement) and ISO 11205 /8/ (measurement of the level of the maximum sound intensity at the workplace point) will not be discussed further in the following sections because they are only applied in special cases.

Earlier investigations as well as those conducted within the framework of this project have shown that the method of approximation according to ISO 11201 and ISO 11202 can lead to considerably greater deviations than that corresponding to the grade of accuracy of the method. The other way around, there are certainly cases in which results determined using ISO 11202 could be allocated to grade 2.

On the whole, the present standards for measurement of the emission sound pressure level are heterogeneous, split up regarding their content and are also in some cases incorrect. For the methods of approximation, the boundaries of applicability that limit the uncertainties according to the specified grade should be specified. Furthermore, all the technical possibilities should be used to be able to benefit from prior knowledge of the machine emission for reduction of necessary time expenditure for the measurement.

Moreover, a reference method should be stipulated for determining the emission sound pressure level in the free sound field according to grade 1. Here, criteria for the measurement environment that adequately restrict the environmental influence should be specified.

Finally, it should be the case that a number of methods are available in order to be able to correct the influence of the room on the measured value at the workplace measuring point with the lowest possible time effort.

2 The dependency of the environmental correction of room properties and emission characteristics

2.1 The important functional dependencies

It is the aim of this investigation to minimize the measurement time effort for determining the emission sound pressure level to the greatest extent possible by including prior knowledge or by using methods of approximation. To achieve this, the functional dependencies between the environmental correction and the influencing parameters must be known, so that a conclusion can be drawn about the uncertainty of the result from the certainty associated with an approximation. These functional relationships will be derived in the following section. In the process, the description of the sound field up to distances that include the allocated workplace will be approximated by the relationships of statistical theory.

The following variables and formula symbols will be used:

A	Equivalent absorption area in m²
A_0	Reference value of the equivalent absorption area (= 1 m²)
L_R	Level of the diffuse sound caused by the room in the case of emission from the source examined
L_p	Emission sound pressure level at the specified position(workplace)
L'_p	Sound pressure level at the specified position not corrected for environmental influence of the room
$\overline{L}$	Mean sound pressure level on the enveloping measurement surface area
$\overline{L}'$	Mean sound pressure level on the measurement surface area not corrected for the influence of the room
L_W	Sound power level
DI	$(= L_p - \overline{L})$ Directivity index of the emission at a specified position related to measurement surface area S
DI'	$(= L'_p - \overline{L}')$ Apparent directivity index determined from the uncorrected measured values related to measurement surface area S
S	Surface area content of the measurement surface area (on which $\overline{L}$ or $\overline{L}'$ has been determined)
S_0	Reference surface area (= 1 m²)

The following dependencies are of interest:

$K_2 = f(A,S)$ and derived from this $A = f(K_2, S)$

$K_3 = f(A, L_{W-p})$ and by analogy $K_3 = f(K_2, L_{W-p})$

$K_3 = f(A, DI)$ and by analogy $K_3 = f(K_2, DI)$

$K_3 = f(A, DI')$ and by analogy $K_3 = f(K_2, DI')$

$K_3 = f(A, L_W, L'_p)$ and by analogy $K_3 = f(K_2, L_W, L'_p)$.

In the following, some of the functional relationships already covered in /10/ will be repeated. This then provides the entire range of relationships for determining the environmental correction K_3.

2.2 The environmental correction K_2

If the sound emitted from one source – in the remainder of the text this source will be referred to as 'machine' – can be quantisized by a sound power level L_W, a mean sound pressure level $\overline{L}$ is caused on a measurement surface area enveloping this machine, for which the following applies

$$\overline{L} = L_W - 10\lg\left(S/S_0 \right) dB \qquad (1)$$

If the source is located in a room, reflections at room boundary surfaces create a room sound field characterized by a level L_R

$$L_R = L_W - 10 \cdot \lg\left(\frac{A}{4A_0} \right) dB \qquad (2)$$

(in the strictest sense, this only applies to rooms in which the requirements of statistical sound field theory are met – in all other cases, it is an approximation that only applies at short distances from the source).
This room sound field overlaps the existing level of the direct sound field at the workplace.
Equation (1) can also be written as

$$10^{0,1 \cdot \overline{L}} = \frac{S}{S_0} \cdot 10^{0,1 \cdot L_W} \qquad (3)$$

(2) also results in

$$10^{0.1 \cdot L_R} = \frac{4 \cdot A_0}{A} \cdot 10^{0.1 \cdot L_W} \qquad (4)$$

In the room, the mean sound pressure level on the enveloping surface area results as the energetic total of these two proportions

$$10^{0,1 \cdot \overline{L}'} = \left(\frac{4 \cdot A_0}{A} + \frac{S_0}{S} \right) \cdot 10^{0,1 \cdot L_W} \qquad (5)$$

with

$$K_2 = \overline{L}' - \overline{L}$$

From (3), (4) and (5) follows

$$\underline{K_2 = 10\lg\left(1 + \frac{4 \cdot S}{A} \right) dB} \qquad (6)$$

This determining equation, which is important for all other equations, applies in the strictest sense due to (2) and (4) only for rooms in which the requirements for statistical sound field theory have been met – in all other cases, it is an approximation that becomes more inaccurate the more the room deviates from these requirements and the greater the measurement surface area S.

2.3 The description of the acoustic room properties

The above-mentioned environmental correction K_2 is all the greater the more the room leads to a level increase on the measurement surface area. The smaller K_2 is for a given machine and/or measurement surface area the more favorable is the room acoustically.

This means that the value of K_2 can be used for sound-related qualification of a room – at least relative to other rooms. In some standards, upper limits are set for this value. If these are exceeded, the measuring method is no longer valid (ISO 11202, for example, may only be applied in rooms where the source concerned leads to a K_2 of a maximum of 7 dB).

By converting (6), you obtain

$$A = \frac{4 \cdot S}{10^{0,1 \cdot K_2} - 1} \qquad (7a)$$

Here, it should be taken into account that S in the numerator of (7a) is the measurement surface area to which the K_2 in the denominator is related.

This relationship can be used to measure an 'effective equivalent absorption area' with the reference sound source.

If the sound power level of the reference sound source is L_W, this results in

$$A = \frac{4 \cdot S}{\frac{S}{S_0} \cdot 10^{0,1 \cdot (\bar{L}' - L_W)} - 1} \qquad (7b)$$

This means that, in principle, there is the possibility to use a reference sound source in the room concerned to determine the mean sound pressure level $\bar{L}'$ on an enveloping surface area S and via (7b) to use the reference sound source specified by the manufacturer to determine the sound power level A.

However, in this process, the sound power level should be translated to the conditions at the measurement point with regard to pressure and temperature.

$\bar{L}'$ is determined on a half sphere measurement surface. Here, the measuring points should be arranged at different heights above the floor to prevent interference effects. A spiral-shaped measurement arrangement in accordance with ISO 6926 /11/ section 7.3.3. is recommended.

Tab. 2.1 Coordinates for determining $\overline{L}'$ on a semi-spherical measurement surface area with radius r

No.	x/r	y/r	z/r
1	0.00	-1.00	0.025
2	0.86	-0.50	0.075
3	0.86	0.50	0.125
4	0.00	0.98	0.175
5	-0.84	0.49	0.225
6	-0.83	-0.48	0.275
7	0.00	-0.95	0.325
8	0.80	-0.46	0.375
9	0.78	0.45	0.425
10	0.00	0.88	0.475
11	-0.74	0.43	0.525
12	-0.71	-0.41	0.575
13	0.00	-0.78	0.625
14	0.64	-0.37	0.675
15	0.60	0.34	0.725
16	0.00	0.63	0.775
17	-0.49	0.28	0.825
18	-0.42	-0.24	0.875
19	0.00	-0.38	0.925
20	0.19	-0.11	0.975

2.4 The environmental correction K_3

2.4.1 The dependency on the emission data

For the following it is important to understand this relationship between sound power level and emission sound pressure level.

If a machine is operated outdoors, a sound field with level L_p is produced at the allocated workplace position that is caused by the individual sound sources depending on the distance and transfer from source point to workplace. The geometrical relation between the positions of workplace and main sources are responsible for the transmission of sound energy and so for the difference between sound power level of the machine and sound pressure level at the workplace (this latter is the emission sound pressure level).

Fig. 2.1 shows a machine with a single point source with sound power level L_W at its outer contour. In Case A, the source is located on the same side as the workplace; in Case B, it is on the opposite side.

The screened position in Case B - despite the same sound power level of the source - results in a considerably lower emission sound pressure level than in Case A. If you comply with the terminology of ISO 9613-2 /12/ and refer to the geometric propagation attenuation as A_{div} and the attenuation due to the screening in Case B as A_{bar}, this results in the following relationship for the two emission sound pressure levels:

$$L_{p1} - A_{bar} - dA_{div} = L_{p2} \qquad (8)$$

Beside the self-screening of the machine structure itself (A_{bar}), the longer propagation path in Case B also leads to an additional reduction (difference in the geometric divergence attenuation dA_{div}).

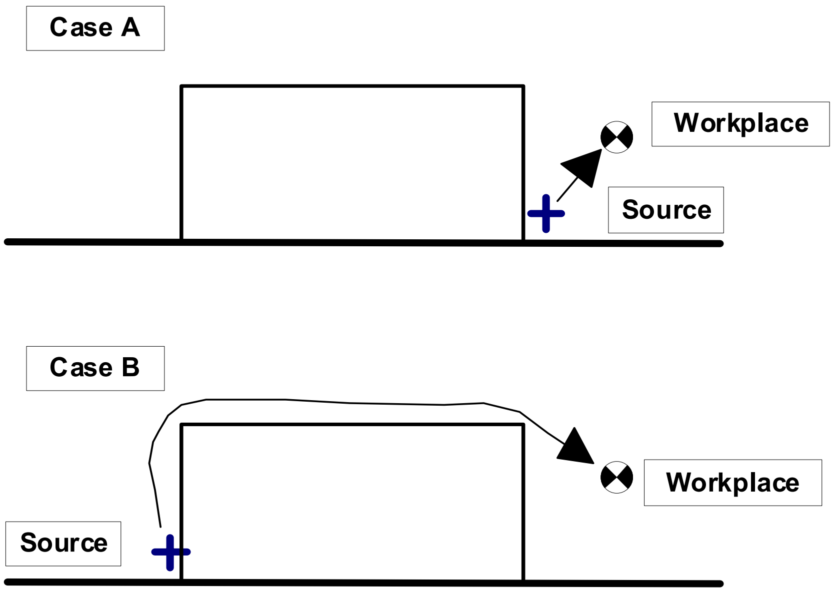

Fig. 2.1 Two cases with the same L_W but different L_p ($L_{w1}=L_{W2}$, $L_{p1}>L_{p2}$)

With the same sound power level in Cases A and B, the result is a considerably lower emission sound pressure level in Case B.

Screening or diffraction is only one of several causes for identical sound power levels resulting in different emission sound pressure levels. Another example is a small source that emits with directivity due to the physics of the sound generation, as it is the case, for example, with the blow-out opening at the end of a pipe. Fig. 2.2 shows the level distribution created in the environment by a directional emitting point source, whereby the lines of the same sound pressure level are shown in 5 dB steps. With a directivity index of DI_0 at 0 degrees and DI_{180} in the opposite direction, there is a difference in the emission sound pressure level of

$$L_{p1} - DI_0 + DI_{180} = L_{p2} \qquad (9)$$

In Case A, the main emission direction is directed towards the workplace point; in Case B, this is the point with the minimum level.

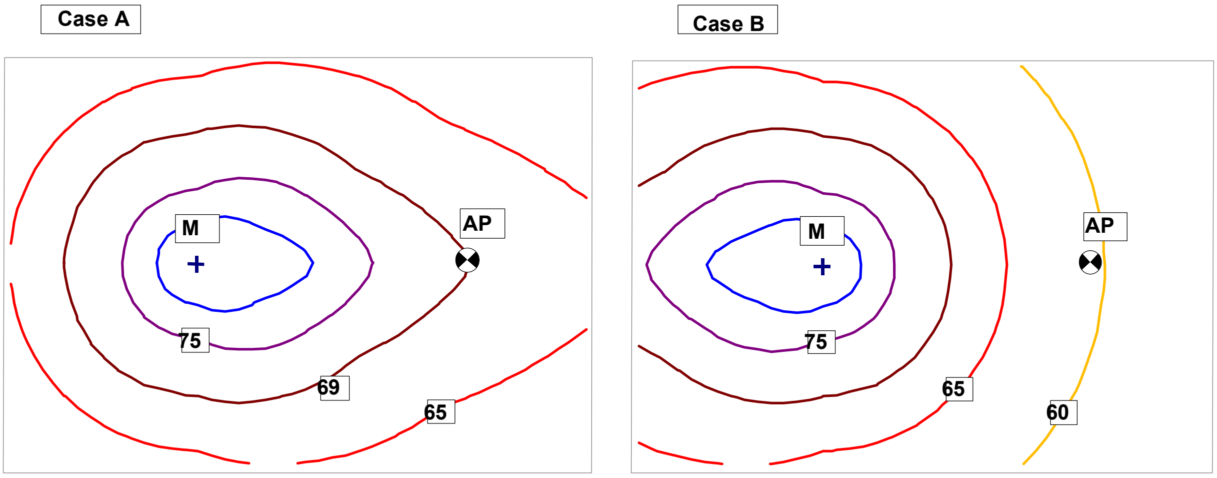

Fig. 2.2 Source M with workplace AP – the same sound power level, but different emission direction

We will now examine the level increase at the workplace point if the machine with emission sound pressure level L_p is operated in a room.

In this case, the reflections at the room boundary surfaces cause an additional room sound field, whose level L_R is calculated using (2) or (4).

The sound pressure level at the workplace in the room results from the overlap of direct sound field and room sound field

$$10^{0.1 \cdot L_p'} = 10^{0.1 \cdot L_p} + \frac{4 \cdot A_0}{A} \cdot 10^{0.1 \cdot L_W} \qquad (10)$$

With (4) and (10), this results in

$$L_p' - L_p = 10 \cdot \lg\left(10^{0.1 \cdot L_p} + \frac{4 \cdot A_0}{A} \cdot 10^{0.1 \cdot L_W}\right) - 10 \cdot \lg\left(10^{0.1 \cdot L_p}\right) \qquad (11)$$

The point-related environmental correction is the difference between the uncorrected and corrected workplace sound pressure level

$$K_3 = L_p' - L_p \qquad (12)$$

If the abbreviation

$$L_{W-p} = L_W - L_p \qquad (13)$$

is used, this environmental correction K_3 can be expressed as

$$K_3 = 10 \cdot \lg\left(1 + \frac{4 \cdot A_0}{A} \cdot 10^{0.1 \cdot L_{W-p}}\right) dB \qquad (14)$$

By inserting (7) in (14), environmental correction K_2 related to the measurement surface area S is used instead of A to characterize the room.

$$K_3 = 10 \cdot \lg\left[1 + \frac{S_0}{S} \cdot \left(10^{0,1 \cdot K_2} - 1\right) \cdot 10^{0,1 \cdot L_{W-p}}\right] dB \qquad (15)$$

The relationship (14) or (15) is important to understand the environmental correction K_3. The emission sound pressure level L_p is known to be the sound pressure level at the workplace that would arise during operation of the machine in the free sound field above reflecting ground (i.e. outdoors). If this machine is now operated in a room characterized by the equivalent absorption area A, a sound pressure level that is higher by K_3 results at the workplace. As the relationship (14) shows, this level increase caused by the room depends only on the room properties via A and on the numerical difference between sound power level L_W and emission sound pressure level L_p.

If you compare the local environmental influence according to (14) with the environmental influence K_2 referring to an enveloping surface area according to (6),

$$K_2 = 10 \cdot \lg\left(1 + \frac{4 \cdot S}{A}\right) dB$$

it can be seen that this local environmental influence additionally depends on the machine emission characteristics via L_{W-p}. In case of a point-related correction, a high L_{W-p} reinforces the second term in the bracket and thus the level increase caused. The same effect of raising the correction has a large measurement surface.

The environmental influence or the level increase at the workplace caused by the environment is thus the same whether a machine with L_W = 90 dB and L_p = 80 dB or a machine with L_W = 50 dB and L_p = 40 dB is operated in a given room.

In the examples shown in Fig. 2.1 and Fig. 2.2, the emission sound pressure level is lower in Case B – which results in a greater environmental influence K_3 than in Case A.

If the sound power level for determining of K_3 is calculated according to (14) or (15) and if this occurs by measurement of the mean sound pressure level on the measurement surface area, the measurement surface area sound pressure level $\overline{L}$ or the directivity index

$$DI = L_p - \overline{L}$$

can be used to determine the environmental correction K_3.

The suitable relationships follow from inserting (3) in (14) or (15)

$$K_3 = 10 \cdot \lg\left(1 + \frac{4 \cdot S}{A} \cdot 10^{-0,1 \cdot DI}\right) dB \qquad (16)$$

as well as

$$K_3 = 10 \cdot \lg\left[1 + \left(10^{0,1 \cdot K_2} - 1\right) \cdot 10^{-0,1 \cdot DI}\right] dB \qquad (17)$$

2.4.2 The dependency of the uncorrected levels or measured values

When measuring the emission sound pressure level, it is necessary to derive the environmental correction K_3 from the variables that are accessible for the measurement *in situ*. These are the directly measurable sound pressure levels at the workplace and on any closed surface enveloping the machine with all sources.

In the following, the derivation of the environmental correction K_3 from the uncorrected sound pressure levels already published elsewhere is repeated, because reference is made later to the individual formulas of the intermediate steps.

The starting point is an emitting sound source in the room with sound power level L_W.
The room is characterized by the equivalent absorption area A.
This results in a sound field caused by the room with a sound pressure level L_R according to (2) or (4).

For the uncorrected and the corrected sound pressure levels at the specified position (workplace), there is the following relationship

$$\begin{aligned} L_p &= 10 \cdot \log\left(10^{0.1 \cdot L'_p} - 10^{0.1 \cdot L_R}\right) dB \\ &= 10 \cdot \log\left(10^{0.1 \cdot L'_p} - 10^{0.1 \cdot \left(L_W + 10 \cdot \log\left(\frac{4 \cdot A_0}{A}\right)\right)}\right) dB \qquad (18) \\ &= L'_p + 10 \cdot \log\left(1 - \frac{4 \cdot A_0}{A} \cdot \frac{10^{0.1 \cdot L_W}}{10^{0.1 \cdot L'_p}}\right) dB \end{aligned}$$

The environmental correction K_3 related to the specified position is the numerical difference between the uncorrected and corrected level

$$\begin{aligned} K_3 &= L'_p - L_p \\ &= -10 \cdot \log\left(1 - \frac{4}{A} \cdot \frac{10^{0.1 \cdot L_W}}{10^{0.1 \cdot L'_p}}\right) dB \qquad (19) \end{aligned}$$

The sound power level results from the uncorrected measured values based on

$$10^{0.1 \cdot L_W} = \frac{S \cdot \sum_{i=1}^{N} 10^{0.1 \cdot L'_p}}{N \cdot \left(1 + \frac{4 \cdot S}{A}\right)} \qquad (20)$$

This results in

$$K_3 = -10 \cdot \log\left(1 - \frac{1}{1 + \frac{A}{4 \cdot S}} \cdot \frac{\frac{1}{N} \cdot \sum_{i=1}^{N} 10^{0.1 \cdot L'_p}}{10^{0.1 \cdot L'_p}}\right) dB \qquad (21)$$

and due to

$$\bar{L}' = 10 \cdot \log\left(\frac{1}{N} \cdot \sum 10^{0.1 \cdot L_p'}\right) dB$$

the environmental correction related to the specified position with

$$K_3 = -10 \cdot \log\left(1 - \frac{1}{1 + \frac{A}{4 \cdot S}} \cdot 10^{-0.1 \cdot \left(L_p' - \bar{L}'\right)}\right) \text{dB} \qquad (22)$$

or

$$K_3 = -10 \cdot \log\left(1 - \frac{1}{1 + \frac{A}{4 \cdot S}} \cdot 10^{-0.1 \cdot DI'}\right) dB \qquad (23)$$

According to (23), K_3 is determined from the uncorrected variables accessible during measurement in the room. Here, the room properties are included via the equivalent absorption area A.

In practice, it can be advantageous to use the environmental correction K_2 related to an enveloped surface area S instead of the equivalent absorption area A. This results from the transformation of (23) and inclusion of (7) in

$$\underline{K_3 = -10 \cdot \log\left[1 - \left(1 - 10^{-0.1 \cdot K_2}\right) \cdot 10^{-0.1 \cdot \left(L_p' - \bar{L}'\right)}\right] dB} \qquad (24)$$

or

$$\underline{K_3 = -10 \cdot \log\left[1 - \left(1 - 10^{-0.1 \cdot K_2}\right) \cdot 10^{-0.1 \cdot DI'}\right] dB} \qquad (25)$$

Determining K_3 to correct the measured value at a single point therefore requires measurement of the sound pressure level on the entire measurement surface area enveloping the machine. This is simply a consequence of the fact that the level at any measurement point actually depends on the total emission of the machine.

Finally, it can be also be helpful if the sound power level, which might have already been ascertained using another method, is included directly. This makes it possible, for example, to measure L_W using a comparative method according to ISO 3747 /15/ and then only to determine the sound pressure level at the workplace at the machine itself.

The corresponding functional link results by changing (12), inserting in (14) and resolution according to K_3 in

$$K_3 = 10 \cdot \lg\left[\frac{1}{1 - \frac{4 \cdot A_0}{A} \cdot 10^{0,1 \cdot \left(L_W - L_p'\right)}}\right] dB \qquad (26)$$

or after replacement of A by K_2 in

$$K_3 = 10 \cdot \lg\left[\frac{1}{1-\frac{S_0}{S}\cdot\left(10^{0,1\cdot K_2}-1\right)\cdot 10^{0,1\cdot\left(L_W - L_p'\right)}}\right] dB \qquad (27)$$

After the transformation, (25) also results in the required relationship

$$DI' = -10 \cdot \lg\left(\frac{1-10^{-0.1\cdot K_3}}{1-10^{-0.1\cdot K_2}}\right) dB \qquad (28)$$

This relationship is required later for assignment of the grade of accuracy to an already determined emission sound pressure level.

3 The acceptable uncertainty in the application of approximate methods

As shown above, correction of the measured value at the workplace to determine the emission sound pressure level requires the determination of the mean sound pressure level $\overline{L}'$ on a measurement surface area enveloping the entire machine.

Another possibility is to determine the sound power level L_W of the machine independent of the emission sound pressure level separately and then to use (19) to determine the environmental correction K_3. This is particularly advantageous if the sound power level can be determined easily or is perhaps even already known. This means that in some cases the sound power level, even on large machines, can be determined according to – or approximately according to – ISO 3747 in an uncomplicated manner and with a few measuring points if the room is adequately reverberant.

Unfortunately this is generally not the case. The measurement on the closed enveloping surface to determine the mean sound pressure level $\overline{\mathrm{L}}'$ only for the reason to derive the environmental correction is a big problem for all users of the standards.

It is therefore required to use methods of approximation to reduce the frequently unacceptable time expenditure. However, this leads to deviations and errors which, depending on the required grade of accuracy, have to be restricted.

The question therefore arises what margin of error can be permitted in determining the emission sound pressure level so that the event can be allocated to grade 2 or 3.

To handle questions of accuracy, the following quantities are used through all standards concerned with noise emission values.

The standard deviation of reproducibility σ_R
This is the standard deviation of noise emission values that are determined with repeated application of the same sound emission measurement method at the same noise source at different times and under different conditions (various laboratories, various operating personnel, various measurement devices).

The uncertainty K
This is a value for measurement uncertainty which, as an added correction to the emission value, defines the upper limit of the range of confidence that the “true” emission value will not exceed this upper limit with a probability of 95%.

Assuming a normal distribution for the total of all emission values, this results in

$$K = 1{,}645 \cdot \sigma_R$$

Regarding accuracy, the existing standards provide the following specifications:

ISO 11201 :
For the standard deviation of reproducibility σ_R, with requirement of grade 2, a maximum value of 2.5 dB is specified. The method may only be applied in rooms in which the environmental correction K_2 does not exceed the value of 2 dB.

ISO 11202:
The maximum standard deviation of reproducibility σ_R is a maximum of 5 dB for grade 3. The method may only be applied in rooms in which the environmental correction K_2 does not exceed the value of 7 dB. The environmental correction K_3 determined using this method may be a maximum of 2.5 dB. If the value determined using the specified method is greater than 2.5 dB, 2.5 dB is used thereafter.

ISO 11204:
The maximum standard deviation of reproducibility σ_R for grade 2 is a maximum of 2.5 dB and for grade 3 a maximum of 5 dB. The method may only be applied in rooms where the environmental correction K_2 does not exceed the value of 7 dB.

ISO 3744 /13/:
This specifies for grades 1 and 2 the standard deviation of reproducibility 1 dB and 1.5 dB. In the case of grade 3, the maximum standard deviation of reproducibility is 3 dB (for K_2 lesser than 5 dB) or 4 dB (for K_2 greater than or equal to 5 dB and lesser than or equal to 7 dB). Determining the sound power level according to grades 1, 2 or 3 requires rooms in which the mean environmental correction K_2 is a maximum of 0.5 dB, 2 dB or 7 dB, as the case may be.

According to the Draft Revision of ISO 3744, Annex A, A.1, K_2 lesser than or equal to 0.5 dB is to be regarded as negligible.

ISO/FDIS 3745: 2002(E) /14/
This draft describes measurement of the sound power level according to grade 1. Due to the prescribed measurement environment - rooms with free sound field above the reflecting level - the environmental influence is minimized. The specified standard deviation of reproducibility related to the A-weighted total level is a value of 0.5 dB.

The estimated value of K for grade 2 is 2.5 dB; for grade 3, 4 dB. This results for (21) in the fact that a mean standard deviation of reproducibility of 1.5 dB or 2.4 dB can be related to grades 2 and 3.

Experience has shown that the environmental influence is the major cause of uncertainties and deviations. Taking into account this experience and the above-mentioned specifications in the individual measurement standards, the following uncertainty caused by the environmental correction is assumed:

0.3 dB for grade 1
1.5 dB for grade 2
3 dB for grade 3

It should be noted at this juncture that the system of grades currently used requires such a rigid allocation. Experience from numerous measurement with sources of known sound power in different measurement environments shows that the actual margin of error in the measurement of sound power levels in individual cases or the uncertainty of the result depend essentially on the amount of the determined environmental correction K_2. Simply speaking it can be stated that about half of the determined environmental correction is uncertain.

The above-mentioned uncertainties related to the grades are used below if the margin of error that is only just acceptable in a grade has to be specified or if the corresponding grade is to determined due to an estimated maximum error.

4 Measurement in the free sound field above reflecting ground – a reference method according to grade 1

4.1 General remarks

Based on the standards of the ISO 11200 series to date, there is no method that would permit the emission sound pressure level to be determined according to grade 1.

This situation should be remedied urgently. If a machine is operated in a measurement environment that has practically no influence on the measured value, there is no reason why the emission sound pressure level determined should not correspond to grade 1.

This would make it possible in disputed cases run a verification, and this would permit a decision with the lowest possible uncertainty.

One possibility is to run the measurement in a room with boundary surfaces that are – with the exception of the reflecting floor plate – designed to be high-absorbing. If the machine is operated in line with its intended purpose in a room of this nature, the environmental influence at the specified measurement point is practically negligible. If the measurement is performed using devices that also correspond to grade 1 according to IEC 60942 /17/, the measurement result can also be assigned grade 1.

Another method that has so far not been taken into account in the standard, but which is frequently used in practice, is to perform the measurement outdoors. This is possible in extended yards and enclosures, parking lots or other asphalt or concrete surfaces if there are no reflecting objects in the immediate proximity and if the other conditions with regard to ambient noise, wind and weather have no relevant influence on the measurement signals.

4.2 Requirements regarding rooms

In line with the specifications in the last section, a room for determining the emission sound pressure level according to grade 1 should have such properties that lead to a deviation from the true value for the measured result value corresponding to a maximum standard deviation of 0.3 dB.

ISO/FDIS 3745 /14/ contains suitable requirements as well as qualification procedures – related to the measurement of the sound power level, however.

As a general principle, a test sound source is used to qualify the room. This is subject to demanding requirements with regard to stability of the tertiary band sound power level and a directivity of the emission that is as low as possible. Starting from this test sound source, the sound pressure levels are measured in one-third octave bands along the diagonal paths.

The deviation of these levels from the 6 dB drop per doubling of the distance is determined for at least 10 points per diagonal path and must not exceed the maximum permitted deviations of the standard stated in Table A.2 of Annex A.

It should be noted that these requirements according to ISO 3745 refer fundamentally to measurement of the sound power level. However, there appears to be no reason why it should not apply to determining the emission sound pressure level.

4.3 Requirements for measurement outdoors

4.3.1 Reflecting objects

For measurement outdoors, it must be ensured that no unacceptable level increases result from reflection.

If one source position and one immission point are assumed, this level increase is a function of

- Reflector position and distance
- Reflector size or expansion
- Degree of absorption or reflection of the reflector surface

The simplest possible arrangement for assessment of reflection influences is shown in Fig. 4.1

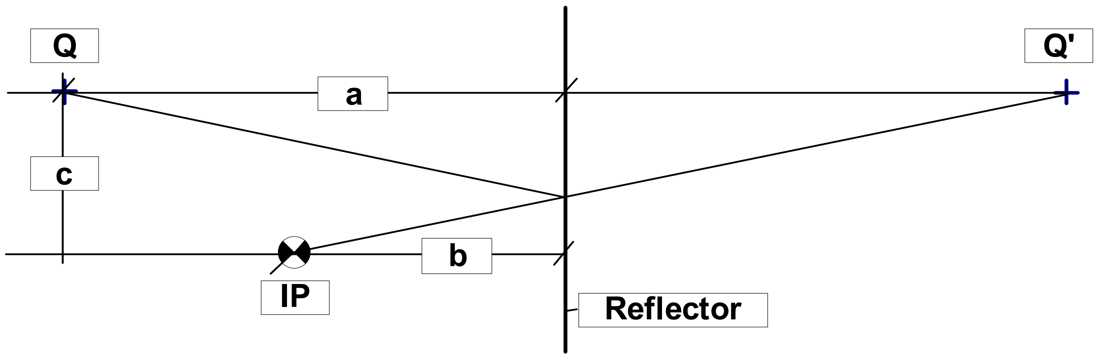

Fig. 4.1 Source Q and immission point IP in front of reflector

A sound source Q and an immission point IP are located at distance a or b and with lateral offset c in front of a reflecting surface area.

The calculation uses the mirror source method, whereby incoherent overlapping is assumed. Interferences are not examined.

If the requirements stated are used to calculate the level increase dL at immission point IP caused by a reflector with degree of absorption α, this results in

$$dL = 10 \cdot \lg\left[1 + (1-\alpha) \cdot \frac{(a-b)^2 + c^2}{(a+b)^2 + c^2}\right] dB \qquad (29)$$

By standardization with c

$$a' = a/c \; und \; b' = b/c$$

this results in

$$dL = 10 \cdot \lg\left[1 + (1-\alpha) \cdot \frac{1 + (a'-b')^2}{1 + (a'+b')^2}\right] dB \qquad (30)$$

To analyze the influence of the distance, a case where the source and immission point are located on a line vertical to the reflector and its absorption is negligible is examined.

In this case, (29) is simplified into

$$dL = 10 \cdot \lg\left[1 + \frac{\left(\frac{a}{b} - 1\right)^2}{\left(\frac{a}{b} + 1\right)^2}\right] dB \qquad (31)$$

This relationship is shown in Fig. 4.2 and Fig. 4.3.

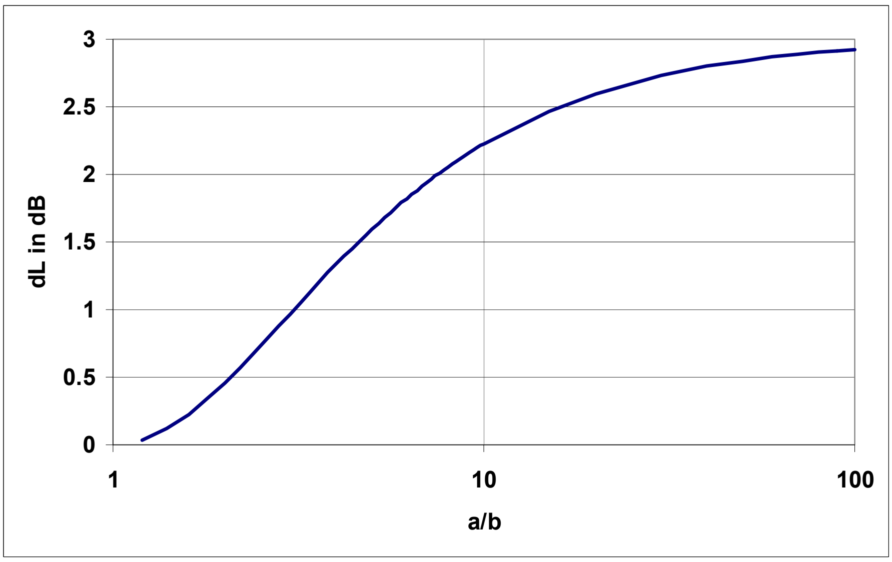

Fig. 4.2 Level increase due to reflector for point source distance < immission point distance

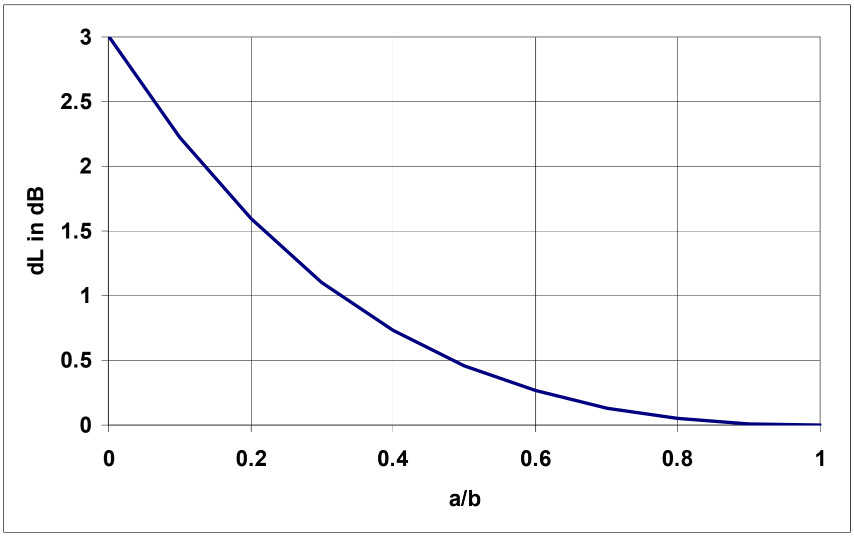

Fig. 4.3 Level increase due to reflector for source point distance > immission point distance

As (31) and the diagram show (in line with expectations), the reflection leads to an addition that approaches the value 3 dB if the ratio source point distance to immission point distance or its reciprocal value becomes very large. From a spatial point of view, this means that the distance from the reflection surface area to the source or immission point becomes very small.

If the reflection surface area is very far removed, the ratio a/b approaches the value 1 and the addition becomes negligibly small.

For normal application in practice, the reflection influence is to be kept below a given limit – according to the above section 0.3 dB. To achieve this, (31) is transformed in such a way that the ratio a/b can be calculated from the desired maximum addition. This conversion results in

$$\frac{a}{b} = \frac{1+\sqrt{10^{0,1 \cdot dL} - 1}}{1-\sqrt{10^{0,1 \cdot dL} - 1}} \qquad (32)$$

with

$$dL = 0{,}3\ dB \qquad (33)$$

resulting from

$$\frac{a}{b} = 1{,}73$$

If the measuring distance

$$d = a - b$$

is inserted, this results in

$$\frac{d}{b} = \frac{1+\sqrt{10^{0,1\cdot dL}-1}}{1-\sqrt{10^{0,1\cdot dL}-1}} - 1 \qquad (34)$$

With (33), this leads to a value of 0.73 for d/b.

In order to ensure an addition through reflections below 0.3 dB, the reflecting surface area must have a distance from the measuring microphone that is at least 1.4 times the measuring distance. This applies to the simple model of the measurement of the sound pressure level caused by a point source.

Also when measuring the emission sound pressure level of machines, level increases can occur due to reflections on reverberant surfaces, but these should remain restricted to below 0.3 dB in the case of a measurement according to grade 1.

An example calculated using a computer shows Fig. 4.4. On a 1 m x 1 m x 1 m machine cubic, 242 point sources are evenly distributed to illustrate a non-directional emission from all sides.

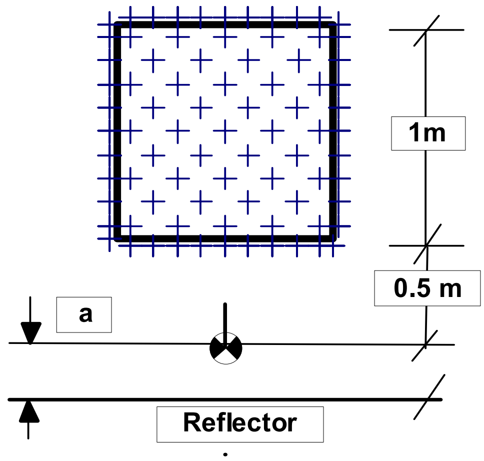

Fig. 4.4 Level increase due to reflector with machine emitting at all sides (model)

To calculate the sound pressure level for the workplace, the contributions of all point sources are summed up energetically. Furthermore, the reflection at the reflecting wall that is also shown is calculated and totaled, including multiple reflection between the wall and machine surface. For the point sources screened against the workplace, the screening measure of the machine cubic is taken into account.

The emissions sound pressure level, including the reflection, has been calculated for the seven distances in specified in Tab. 4.1.

Tab. 4.1 Calculation results for reflector near immission point

Distance Reflector-Point IP m	Level L dB(A)	Level increase by reflector dB
0.05	92.0	3.2
0.1	91.7	2.9
0.25	90.9	2.1
0.5	90.0	1.2
1	89.4	0.6
2	89.1	0.3
4	88.9	0.1
no reflector	88.8	

Tab. 4.1 shows that the level increase caused by the reflection reaches 0.3 dB if the reflector is 2 m away from the workplace. The factor of the distance reflector immission point to 'measuring distance' workplace-machine is thus 4.

These results certainly do not apply in general for all geometric relationships.

Fig. 4.5 and Fig. 4.6 show a model machine with dimensions 5 m x 1 m x 2 m, whereby the uniform emission is achieved by means of 573 point sources distributed across the machine surface with a total sound power level of 100 dB(A).

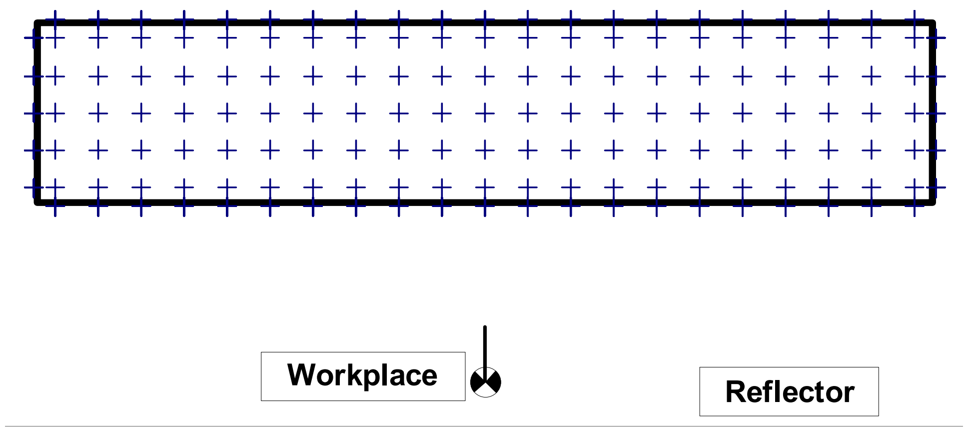

Fig. 4.5 Simulation: Machine with uniform emission and reflector - workplace in 1 m distance in front of the long side

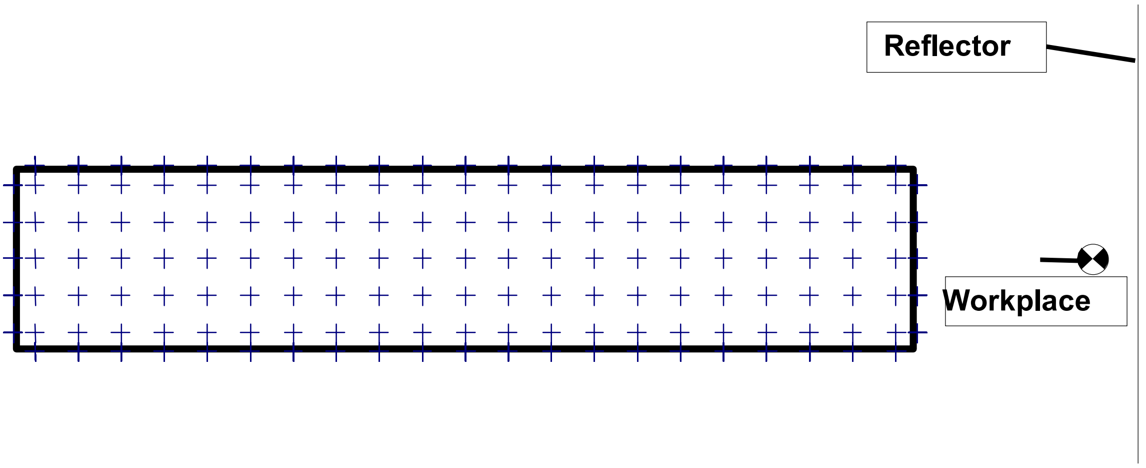

Fig. 4.6 Simulation: Machine with uniform emission and reflector - workplace in 1 m distance in front of the narrow side

The contribution of all point sources as well as the mirror sound sources are summed up energetically to calculate the sound pressure level for these two cases, taking account of the screening by the machine cubic itself.

In this very complicated case, even higher sound pressure levels arise at the workplace point if the multiple reflection between the reflector and facing machine side are included. This is the case when this machine side itself has an acoustically 'smooth' surface and a relevant proportion of the sound power that strikes it is reflected (mirrored).

Tab. 4.2 Results of the calculation of the workplace sound pressure level with reflector - workplace in 1 m distance in front of the machine broadside

Distance Reflector-Point IP	Level in dB For calculation up to order		Level increase in dB For calculation up to order	
m	1	5	1	5
0.05	86.3	88.8	1.7	4.2
0.1	86.2	88.6	1.6	4.0
0.25	85.9	88.1	1.3	3.5
0.5	85.6	87.4	1.0	2.8
1	85.2	86.5	0.6	1.9
2	84.9	85.5	0.3	0.9
4	84.7	84.9	0.1	0.3
6	84.6	84.7	0.0	0.1
no reflector	84.6	84.6		

Tab. 4.3 Results of the calculation of the workplace sound pressure level with reflector - workplace in 1 m distance in front of the machine narrow side

Distance Reflector-Point IP m	Level in dB For calculation up to order 1	5	Level increase in dB For calculation up to order 1	5
0.05	83.1	84.4	1.5	2.8
0.1	83.0	84.1	1.4	2.5
0.25	82.7	83.5	1.1	1.9
0.5	82.4	82.8	0.8	1.2
1	82.1	82.4	0.5	0.8
2	81.9	82.0	0.3	0.4
4	81.7	81.8	0.1	0.2
6	81.7	81.7	0.1	0.1
8	81.6	81.6	0.0	0.0
no reflector	81.6	81.6		

However, even these very extreme geometries show that a factor of the distance reflector-immission point to the measuring distance of 4 is sufficient to ensure compliance or undershooting of a level increase of 0.3 dB caused by reflection.

Finally, we will examine the very special extreme case that with the same 5 m long machine as described above the major noise emission takes place at the front side farthest away from the workplace, which is therefore screened.

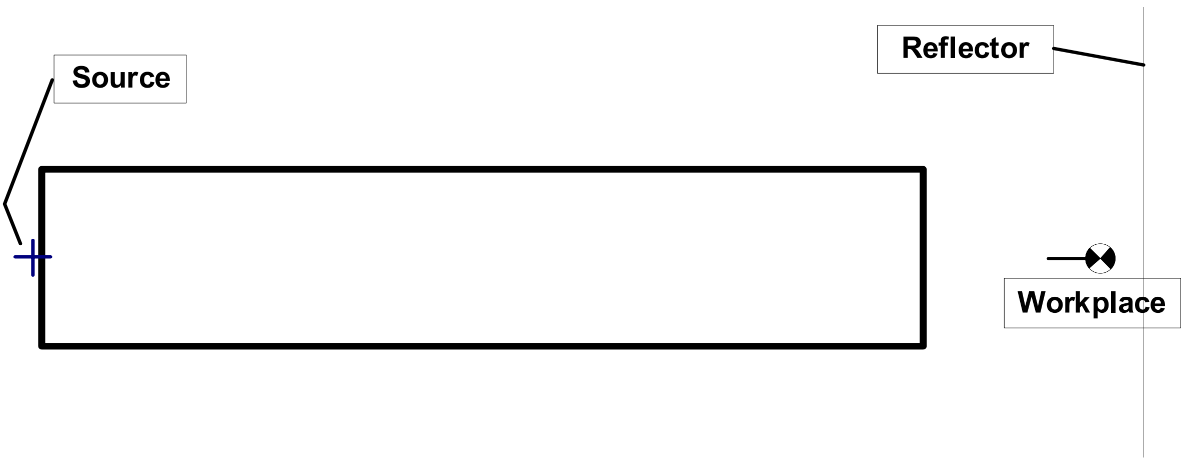

Fig. 4.7 Simulation: Machine with one-sided emission and reflector - workplace in 1 m distance in front of the narrow side

The calculation takes account of the diffraction above the deck and around the two outer edges of the machine cubic as well as the reflection of the diffracted sound at the reflecting wall. The calculated levels at the workplace depending on the distance reflector-workplace as well as the level increase caused by the reflector are summarized in Tab. 4.4.

Tab. 4.4 Results of the calculation of the workplace sound pressure level with reflector - workplace in 1 m distance at the machine narrow side opposite the source

Distance Reflector - Source m	Level L dB(A)	Level increase by reflector dB(A)
0.05	73.4	5.8
1	70.2	2.6
2	69.6	2
4	68.8	1.2
6	68.4	0.8
8	68.1	0.5
10	68	0.4
no reflector	67.6	0

The results shows that in these cases – noise emission facing away from the workplace – the above-mentioned factor 4 is on the safe side. In this case, even factor 2 would be adequate.

The situation is different if the reflecting surface area in the latter case is located on the source side.

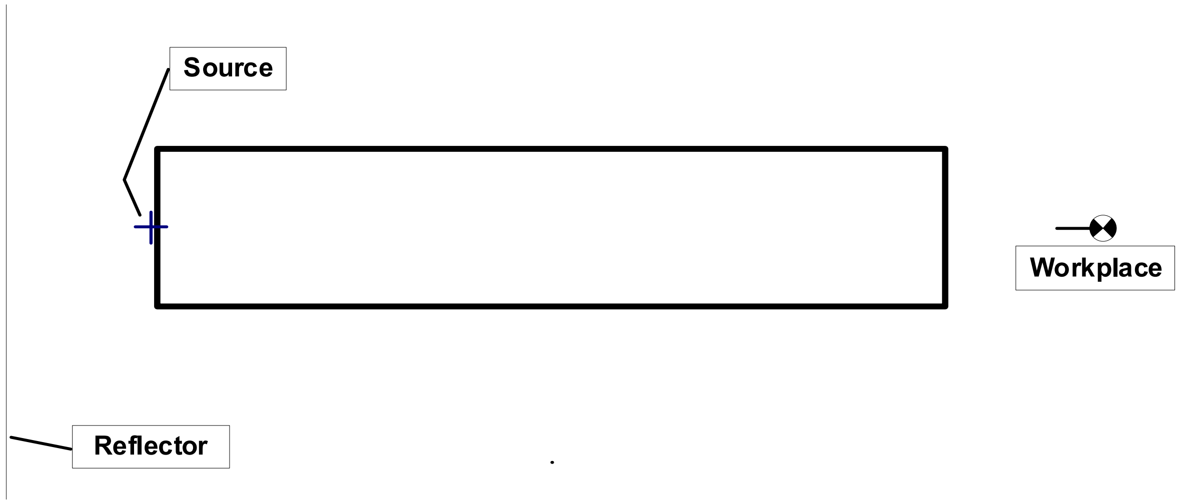

Fig. 4.8 Simulation: Machine with one-sided emission and reflector - workplace in 1 m distance at the narrow side, reflector opposite

Tab. 4.5 Results of the calculation of the workplace sound pressure level with reflector on the source side

Distance Reflector-Point IP m	Level L dB(A)	Level increase by reflector dB
0.05	67.2	0.6
1	67.0	0.4
2	66.9	0.3
4	66.7	0.1
6	66.7	0.1
8	66.7	0.1
10	66.6	0.0
no reflector	66.6	

The sound that influences the workplace with free propagation is weakened by the diffraction above the machine cubic. The reflected sound, which therefore originates from a more remote mirror source, is weakened due to this geometric constellation to a lesser degree the further away the reflector is. Higher attenuation due to the longer propagation path and lower attenuation due to screening by the machine cubic are therefore opposed with enlargement of the distance machine - reflector. The consequence is that a reflector in this arrangement has to be considerably further away so that the level increase it causes falls short of a given maximum value.

This is also the reason why the specified level addition caused by the reflection only reaches 0.3 dB at a reflector distance of over 10 m (in this case from the source).

Finally, the question arises as to whether determining a minimum distance for reflecting surfaces is possible at all, as a number of these surfaces can be present.

In this context, the configuration with the cubic machine measuring 1 m x 1 m x 1 will be examined once again. With a reflector-workplace distance of 3 m, another reflector on both the right and left at the same distance will be included in the calculation.

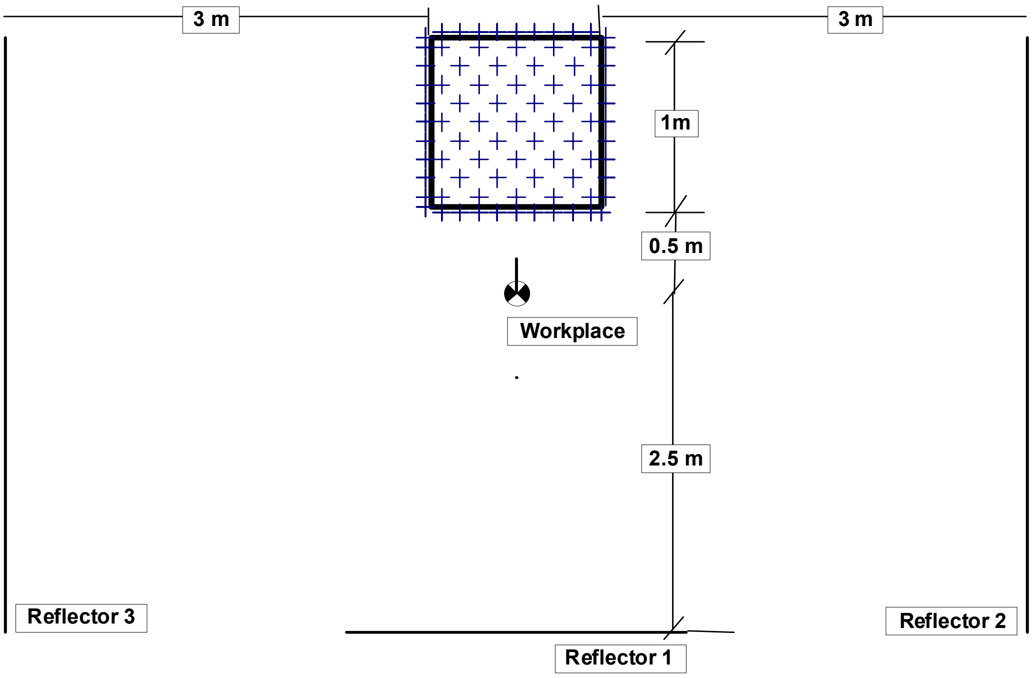

Fig. 4.9 Machine with 3 reflecting surface areas at a distance of 3 m

The calculation is performed with both a reflection of the 1st order as well as with all reflections up to the 5th order, because in this case multiple reflections between the reflector and the outer surfaces of the machine can also play a role.

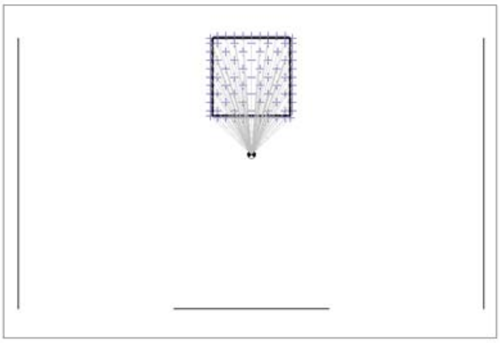

Fig. 4.10. Only direct sound

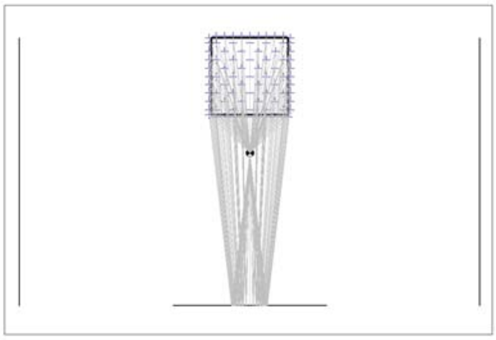

Fig. 4.11 Reflection of the 1st order at reflector 1

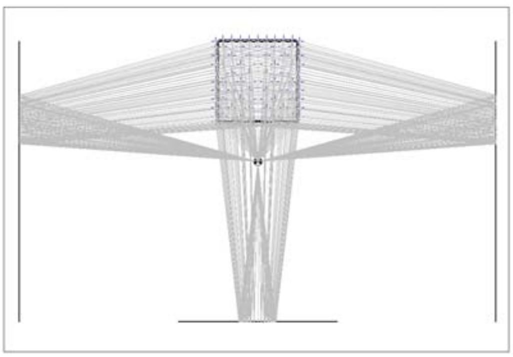

Fig. 4.12 Reflection of the 1st order at reflector 3

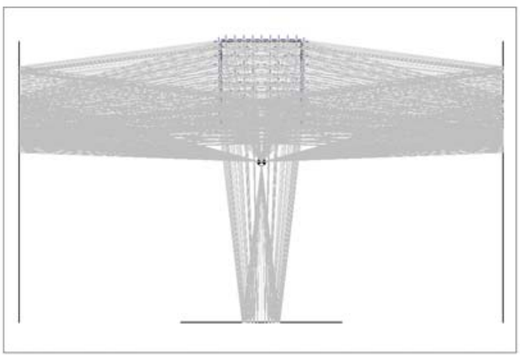

Fig. 4.13 Reflection of the 2nd order at 3 reflectors

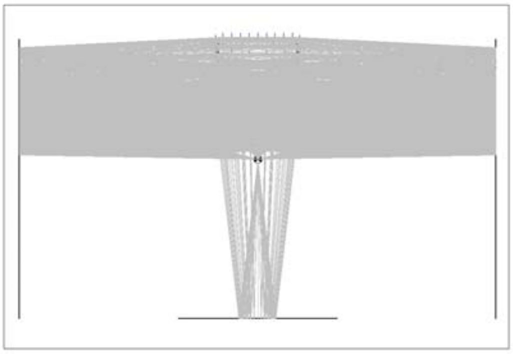

Fig. 4.14 Reflection of the 5th order at 3 reflectors

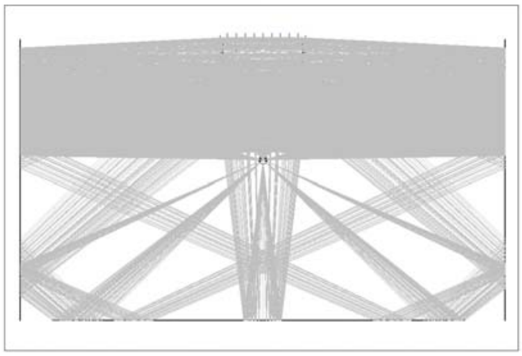

Fig. 4.15 Reflector 1 enlarged

Fig. 4.10 to Fig. 4.15 show the various arrangements that have been calculated. The more reflectors are integrated the greater the probability that also higher reflection orders can play a major role.

The fact that this effect caused by several reflection surfaces as regards acoustics should not be overestimated is shown in the calculation results in Tab. 4.6.

Tab. 4.6 Calculation involving several reflectors

Number of reflectors	**Level in dB For calculation up to order**		**Level increase in dB For calculation up to order**	
	1	**5**	**1**	**5**
0	**88.8**			
1	**89.0**	**89.1**	**0.2**	**0.3**
2	**89.1**	**89.2**	**0.3**	**0.4**
3	**89.3**	**89.4**	**0.5**	**0.6**
3, Refl. 1 widened	**89.3**	**89.7**	**0.5**	**0.9**

The level increase due to several reflectors is only a few tenths of a dB. It is only when the widening of reflector 1 practically creates a kind of partial room that multiple reflection leads to a level increase of approx. 1 dB.

The analyses until now referred to the fact that every geometrically possible reflection makes a level contribution equivalent to the longer propagation path of the reflected emission – the degree of reflection deviating from 1 of the reflecting surface and its dimension have not been taken into account.

With regard to the degree of reflection, this also makes sense – with generally standardized specifications, the least favorable case should be included. The reflector can also be a smooth-painted concrete surface.

A reflector must have a minimum expansion vertical to the emission direction so that the sound wave striking it is reflected without being weakened. Standardized specifications of ISO 9613-2 /12/ can be used as the basis here.

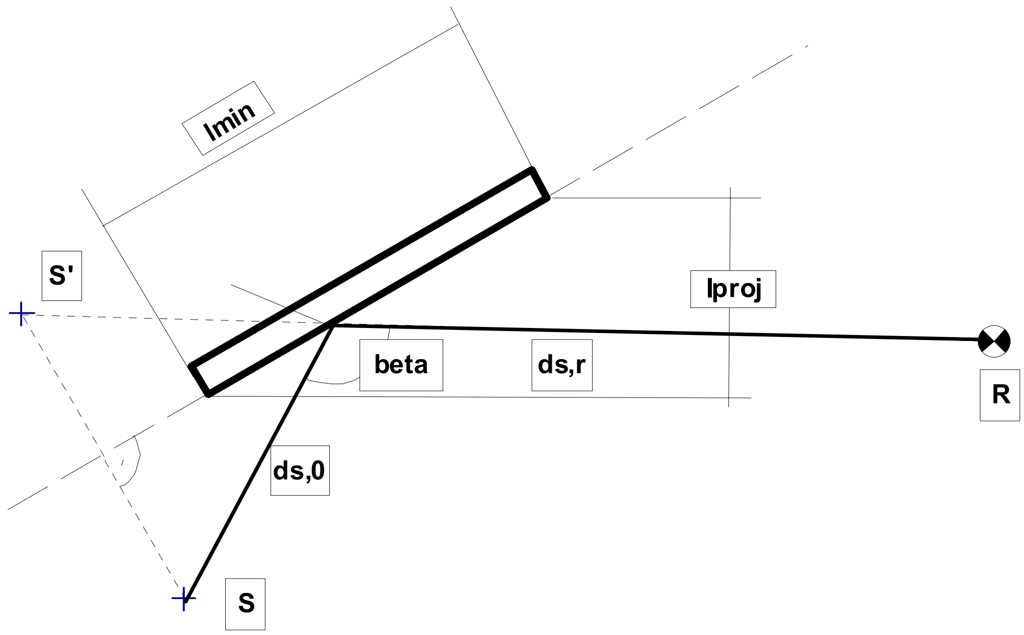

Fig. 4.16 The geometric relationships for setting the required reflector size

A reflection contribution is only to be taken into account for the frequency bands for which the following applies

$$\frac{1}{\lambda} > \left[\frac{2}{(l_{\min} \cdot \cos \beta)^2}\right] \cdot \left[\frac{d_{s,0} d_{0,r}}{d_{s,0} + d_{0,r}}\right] \qquad (35)$$

with

λ Wavelength in meters

$d_{s,0}$ Distance between source and reflection point on the obstacle
$d_{0,r}$ Distance between reflection point on the obstacle and receiver
β Angle of incidence in radiant

l_{proj} Min. expansion of the reflector in projection direction of the emission
l_{min} The expansion of the reflector in the direction in which the smallest l_{proj} results

4.3.2 Wind and meteorology

Quantitatively assessable indications of meteorological conditions that are to be adhered to for measurement of the emission sound pressure level outdoors were not found.

Wind:
Although the measuring distances are small for determining the emission sound pressure level with regard to sound propagation, it is recommended to perform measurements to achieve results of grade 1 only when there is no wind or wind speeds < 1.5 m/s.

Rain:
Measurements during any type of precipitation are not to be permitted.

Temperature, humidity and pressure:
These general conditions or the permitted values of these parameters arise from the specifications of the measurement devices used. With regard to the measurement results, there is a conversion to standard conditions based on 7.4.

4.4 Conversion to standard conditions

The sound pressure level measured at the workplace of a machine under free field conditions depends to a low degree on the air pressure and ambient temperature. For measurement according to grade 1, this systematic influence should be eliminated by conversion to standard conditions.

According to Wittstock (derivation, see Appendix), the emission sound pressure level converted to standard conditions results from

$$L_{p,N} = L_p - 25 \cdot \lg\left(\frac{B}{B_N}\right) dB + 20 \cdot \lg\left(\frac{T}{T_N}\right) dB \qquad (36)$$

with

$L_{p,N}$ Emission sound pressure level at standard conditions
L_p Emission sound pressure level determined at air pressure B and temperature T
B Air pressure in Pa for determining the emission sound pressure level
B_N Air pressure in accordance with standard condition $1{,}01325 * 10^5$ Pa
T Temperature in K for determining the emission sound pressure level
T_N Temperature in accordance with standard condition 296,15 K

5 Determining the directivity index

5.1 The value range of directivity indices

As explained in 2.4.1 and 2.4.2 with (22) and (24), the environmental correction K_3 is influenced not only by the room properties but also by the directional characteristics of the machine emission. Equations (17) and (25) show this considerable dependency quantitatively.

Finally the difference between K_2 – which refers to a measurement surface enveloping the machine entirely – and K_3 - referring to a point or area - depends only on the difference between the mean sound pressure level on this measurement surface and that at the point or in the area.

The directivity index DI is the difference between emission sound pressure level and measurement surface sound pressure level - it refers to free field conditions and can thus be regarded as a machine property.

Directional emission can arise in different ways. For example, the noise generation process itself can be responsible, as is the case with volume sources (monopolar), oscillating plates (dipolar) or air swirls (quadrupolar). With machines as sources, these mechanisms only seldom lead to major directivity, as the noises are usually wide-band and created by more extended source areas.

Another major reason for directional emission that occurs more frequently is the screening by acoustically impermeable structures. For example, a number of machines can be regarded as an arrangement of sound-reflecting cubics whose surface emits sound in partial areas or noise-emitting elements are located in front of their – reflecting – surface.

This latter case can be investigated using simulation calculations. Here, the machine structure is assumed to be acoustically impermeable and the emitting areas are simulated by point, line and surface sound sources. The immission points can be arranged in any way, which enables a great many investigations ranging from determining the emission sound pressure level with a given source distribution to establishing the sound power level using the enveloped surface area method.

However, when this type of computer simulation is applied, it must be taken into account that all the phenomena associated with phase relations – e.g. interference between direct sound and ground reflection – cannot be investigated, as exclusively the sound power transport is included in the calculation. Frequency-dependent attenuations e.g. due to reflection or diffraction, however, are taken into account. The techniques used for the simulation calculation are described in Appendix 10.2.

An example of practically occurring directivity indices due to self-screening of the machine structure was investigated using Fig. 5.1.

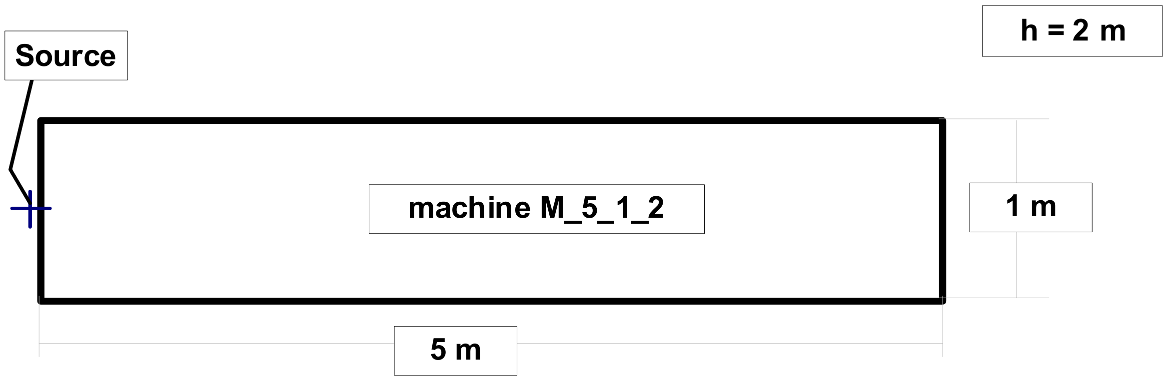

Fig. 5.1 Machine 5 m x 1 m x 2 m with a point source at the narrow side

The sound propagation calculation for this extreme case of an emission area that is only small at the front results in the directivity index shown in Fig. 5.6.

The point source was assigned a sound power level of 100 dB(A). The calculation at the immission points in accordance with Fig. 5.2 to Fig. 5.5 – these correspond to the measuring point arrangement for determining the sound power level according to ISO 3744 – results in a measurement surface sound pressure level of 81 dB(A).

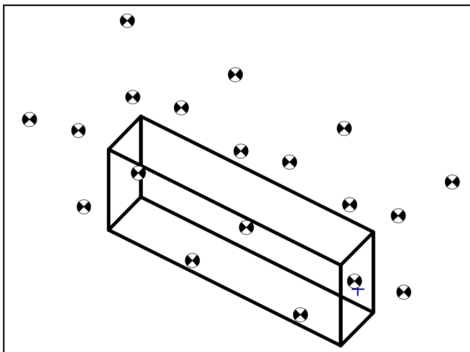

Fig. 5.2 Oblique view for measuring point arrangement, cubic according to ISO 3744

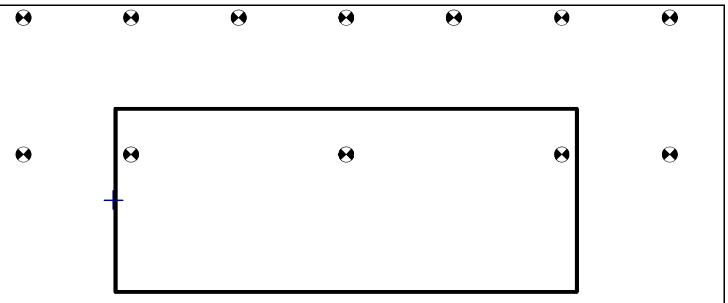

Fig. 5.3 Side view

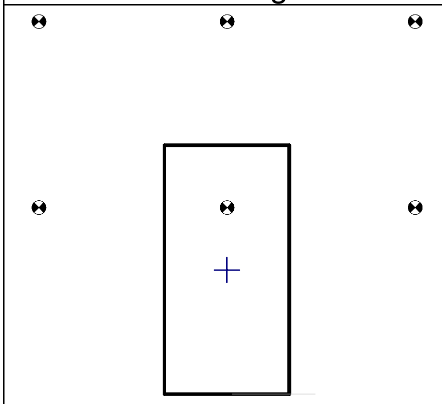

Fig. 5.4 Frontal view

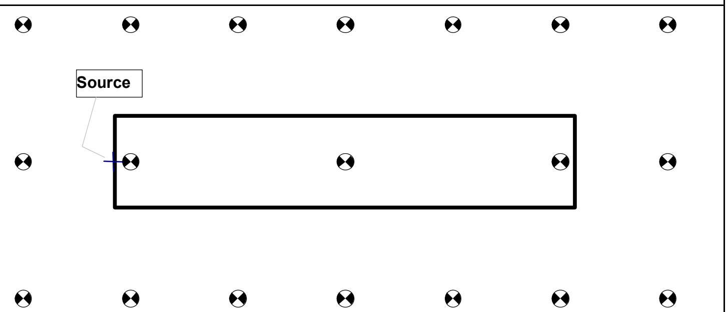

Fig. 5.5 Top view

With this arrangement, the directivity indices shown in Fig. 5.6 are determined at the immission points arranged 0.5 m apart at a distance of 1 m from the path surrounding the machine.

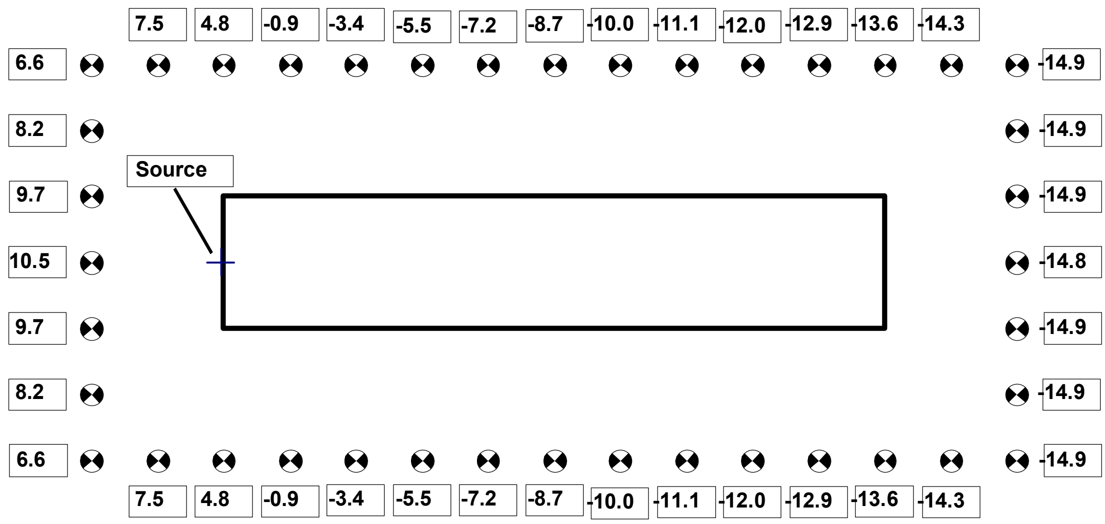

Fig. 5.6 Directivity indices DI on a surrounding path at 1 m measuring distance, determined in the free sound field

The example shows that directivity indices of up to –15 dB result in the screened area. This value comes about as a result of both the screening by the machine structure and the great distance to the sound source (geometric divergence attenuation).

If the same machine is now operated in a room with the dimensions 10 m x 10 m x 6 m and a mean absorption coefficient of 0.2, the sound power level of the machine leads to a room sound pressure level of 86.6 dB(A).

The calculation at the cubic measuring points in accordance with the arrangement in Fig. 5.2 leads to an apparent measurement surface sound pressure level $\overline{L}'$ of 87.6 dB(A) as a result of the additional influence of this room sound field. The apparent directivity index DI' determined on the surrounding measuring path in the room is shown in Fig. 5.7.

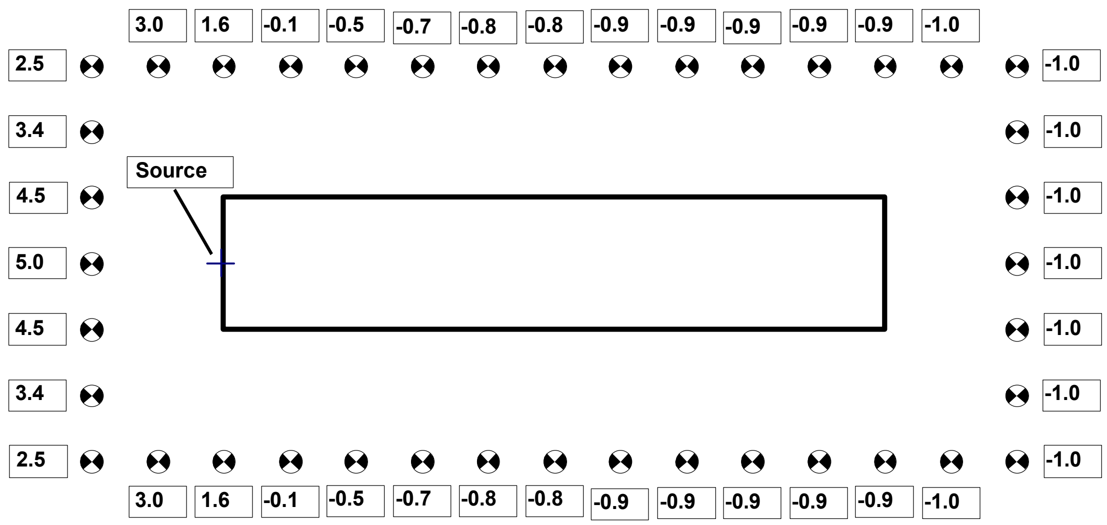

Fig. 5.7 Apparent directivity index DI' on a surrounding path at 1 m measuring distance in the room 10 m x 10 m x 6 m with mean degree of absorption 0.2

A comparison of Fig. 5.6 and Fig. 5.7 shows clearly how the directivity index related to free sound field is 'smoothed' when the machine is operated in the room – the apparent directivity indices determined in the room assume considerably lower values.

If the sound pressure level is now to be measured at the workplace with the machine in operation and the emission sound pressure level is to be determined by subtracting the correction K_3 and the directivity index DI measured in the free sound field according to Fig. 5.6 is known, formula (17) is to be used; with the apparent directivity index DI' measured in the room according to Fig. 5.7, formula (25) is to be used.

In the extreme case shown, in which a 5 m long machine is located in a room with 10 m length and width without absorption paneling, the room sound field covers - in a manner of speaking - all the areas with low or negative directivity indices. With a K_2 of approx. 7 dB, the dependency shown in Fig. 5.8 of the K_3 correction results from the established directivity index DI or DI', as the case may be.

The diagram shows clearly that more negative apparent – i.e. measured in the room – directivity indices than –1 dB practically cannot occur in this case. This value at the areas of the measurement surface exposed to the least noise is determined by the room sound field, thus forming the lower end point of the scale of possible values.

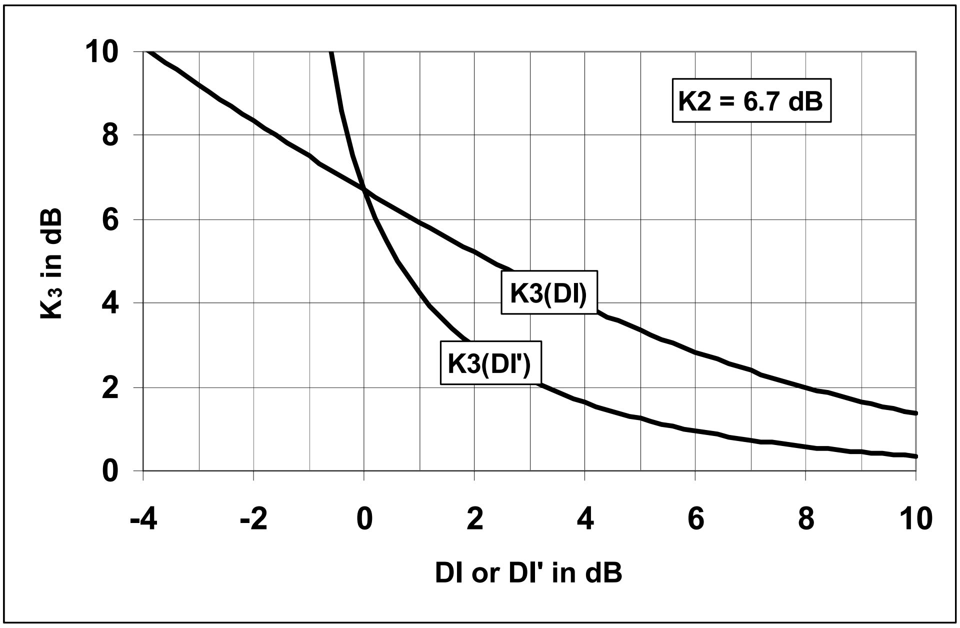

Fig. 5.8 The dependency of the point-related environmental correction K_3 on the directivity index DI (free sound field) and on the apparent directivity index DI' (in the room)

The diagram also illustrates the problem of point-related environmental correction if K_3 is to be determined in areas with low apparent directivity index – it is obvious that the uncertainty of the method increases considerably here.

The smaller K_2 is, the less critical is the steep rise of this curve with declining directivity index. Fig. 5.9 referring to a K_2 of 2 dB shows this clearly – uncertainties in determining the directivity index would be considerably less noticeable here.

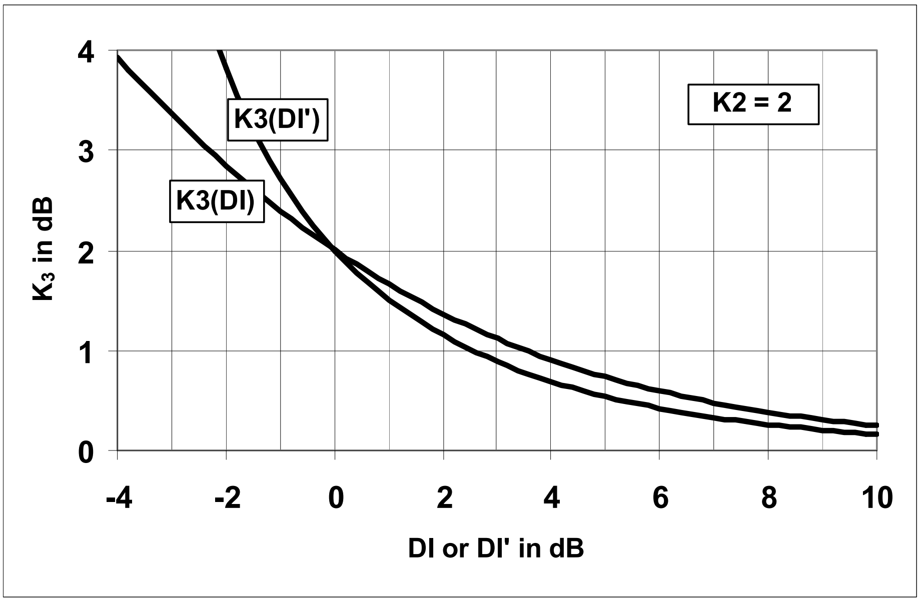

Fig. 5.9 The dependency shown in Fig. 5.8 - here referring to a K_2 of 2 dB

5.2 Approximate determination of the directivity index

To simplify the measuring method, it is important to determine the directivity index at the workplace of a machine without having to perform a measurement at all points of a measurement surface enveloping the machine.

This directivity index can definitely not be estimated – at least not in the standardized area. It will be important to use as few additional measurements as possible to obtain an approximate value whose absolute deviation from the true value is more or less given a 'ceiling' by an upper limit X. The application of this upper limit in addition to the estimated value the indicates the uncertainty of the result.

According to this proposal, the approximated directivity index $DI'_{j,approx}$ is specified in such a way that the sound pressure level at the specified position or at the workplace is determined exactly and the mean sound pressure level referring to the measurement surface S is determined approximately.

$$DI_{j,approx} = L_j - \overline{L}_{approx} \qquad (37)$$

$$DI'_{j,approx} = L'_j - \overline{L}'_{approx} \qquad (38)$$

If the mean level on the measurement surface is determined approximately using a few points, the margin of error in determining the actual or apparent directivity index is identical to this that occurs in determining this mean measurement surface level.

$$\Delta DI_j = \Delta\overline{L}$$

$$\Delta DI'_j = \Delta\overline{L'}$$

To approximately determine the directivity index $DI_{j,approx}$ referring to the free sound field or the apparent measurement surface sound pressure level $\overline{L}'_{approx}$, the following methods can be applied as a general principle.

1) At a distance of 1 m in front of the center of each side of the reference cubic, the sound pressure level is determined – the approximate measurement surface sound pressure level is the energetic mean of these 4 values

2) With considerable deviation of the two dimensions from one another, the 4 values are weighted for averaging according to the size of the side.

3) The measurement takes place on walking around the machine by temporal integration of the continuously measured sound pressure level.

Methods 1 and 2 can be used both with and without inclusion of the top side. If a machine is built in such a way that it mainly emits upwards, this top surface area is to be taken into account in the same way as the 4 sides.

Example 1: Simulation calculation for small machine

The three methods mentioned are applied using the machine M_1_1_1 shown in Fig. 5.10 with directional emission. In the first step, the measurement surface sound pressure level is determined on a cubic surface area in 1 m measuring distance. Due to the strong directivity, a 0.25 m grid spacing is selected for the calculation points.

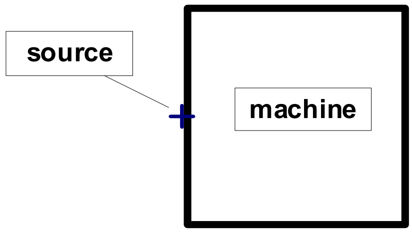

Fig. 5.10 Small machine with one-sided point source – directivity due to self-screening

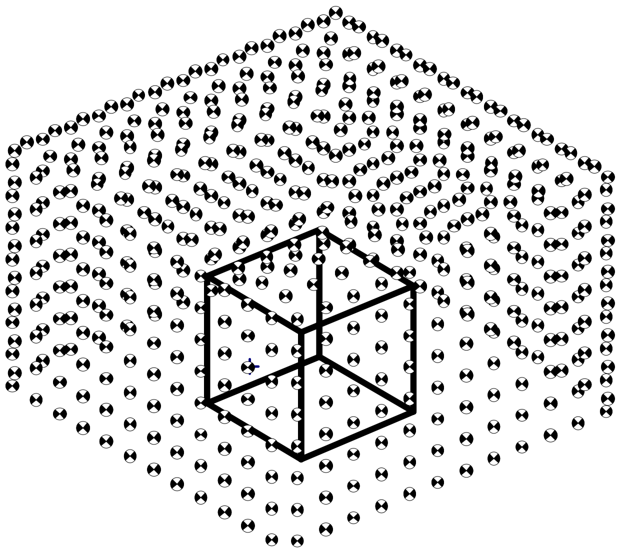

Fig. 5.11 Cubic measuring surface for simulation calculation

The measurement surface sound pressure level determined on this cubic measuring surface is 84.8 dB(A).

1) The calculation at 4 points in front of the side centers results in the values shown in Fig. 5.12.

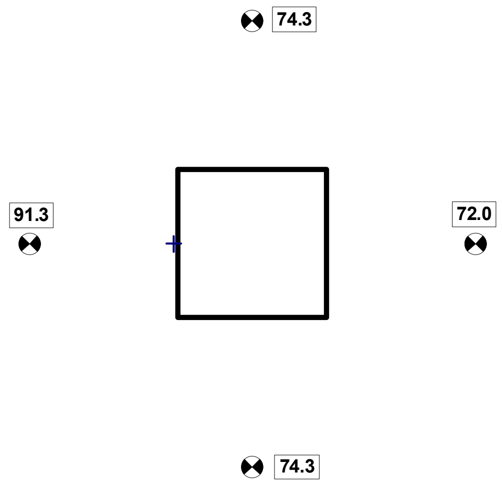

Fig. 5.12 Calculation of the levels in front of the side centers

The approximate value for the measurement surface sound pressure level resulting from this is 85.4 dB(A).

2) As the sides are the same size, weighting with the surface area sizes leads to the same result.

3) Determining the level on a closed path around the machine at a distance of 1 m results in the following values:

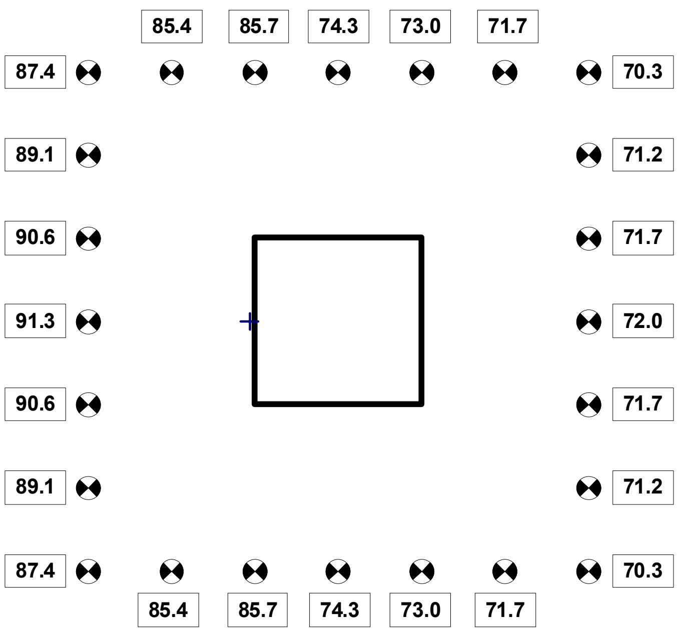

Fig. 5.13 Calculation of the level on a surrounding measuring path

Averaging these level results in an approximate value for the measurement surface sound pressure level of 85.2 dB(A).

Example 2: Simulation calculation for large machine

The machine M_5_1_2 described above with a frontal sound source and thus a strong directivity is investigated (machines with strong directivity represent a 'worst case' analysis and provide an upper limit of the possible approximation error due to methods of approximation).

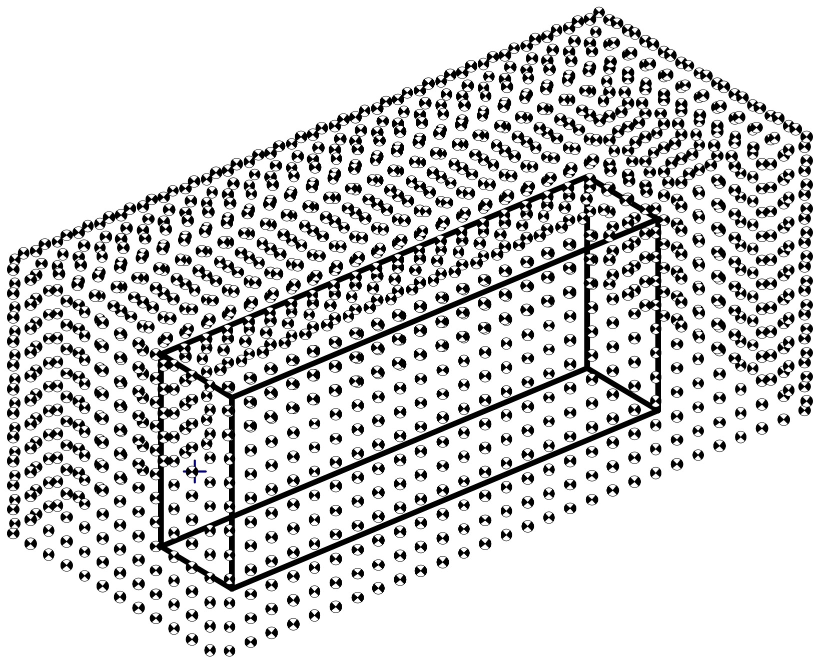

Fig. 5.14 Cubic measuring surface for simulation calculation

The resulting measurement surface sound pressure level for this 'virtual' machine is 81 dB(A).

1) The calculation in front of the four side centers results in the values shown in Fig. 5.15 – the mean sound pressure level determined from this is 85.5 dB(A).

Fig. 5.15 Simulation calculation at each point in front of the side centers

2) Weighting with the side lengths results in a mean sound pressure level of 85.9 dB(A).

3) The mean level determined by stepping around the machine and continuous integration is determined by means of a simulation calculation at 40 points arranged at a constant distance to one another and subsequent averaging.

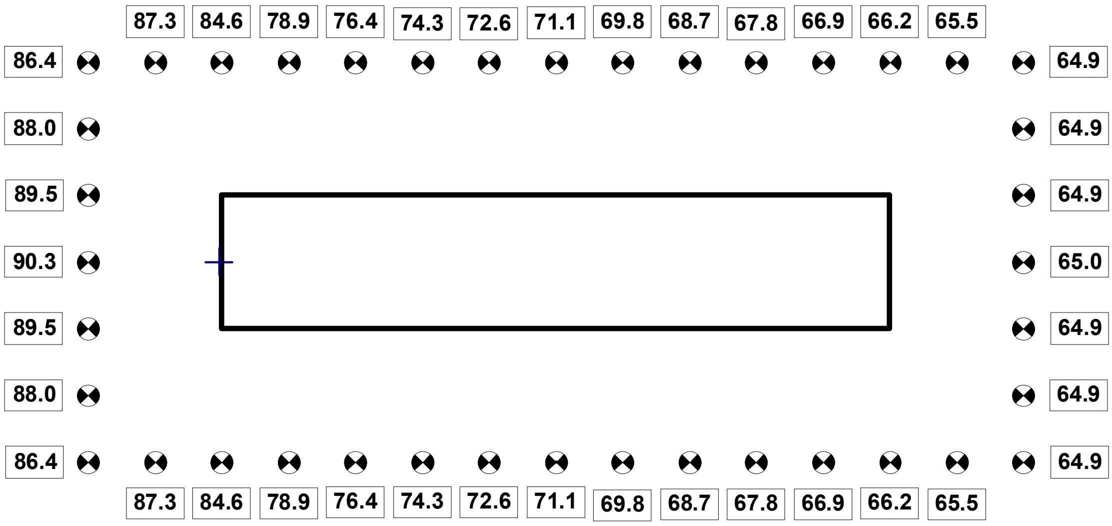

Fig. 5.16 The sound pressure level determined on the surrounding path

This results in a mean level of 82.5 dB(A).

On the whole, it can be stated that the examples certainly provide extremely unfavorable values because the emitting point source is positioned at the center of the side and therefore also exactly at the shortest distance in front of the immission point allocated to this side.

Example 3: Measurement on a model machine

Finally, a real measurement is to be included. /18/ describes a test in which a van was regarded as a model machine and tested in the free sound field as well as in a number of industrial halls with regard to its noise emission.

A sound generator was built into the van, emitting a wide-band noise. With the windows closed, the vehicle was a non-directional emitting model machine; with the driver's window opened, it was a strongly directional emitting model machine. The measurement was carried out on a cubic measuring surface in accordance with ISO 3744 at 1 m measuring distance.

Both in the free sound field and in the industrial halls, a frequency spectrum was measured and recorded at each of the 94 measuring points.

Within the framework of this investigation, measurement in the free sound field is used as the worst case. It is intended to assess what margin of error results from determining the measurement surface sound pressure level when one of the previously mentioned approximation strategies is used.

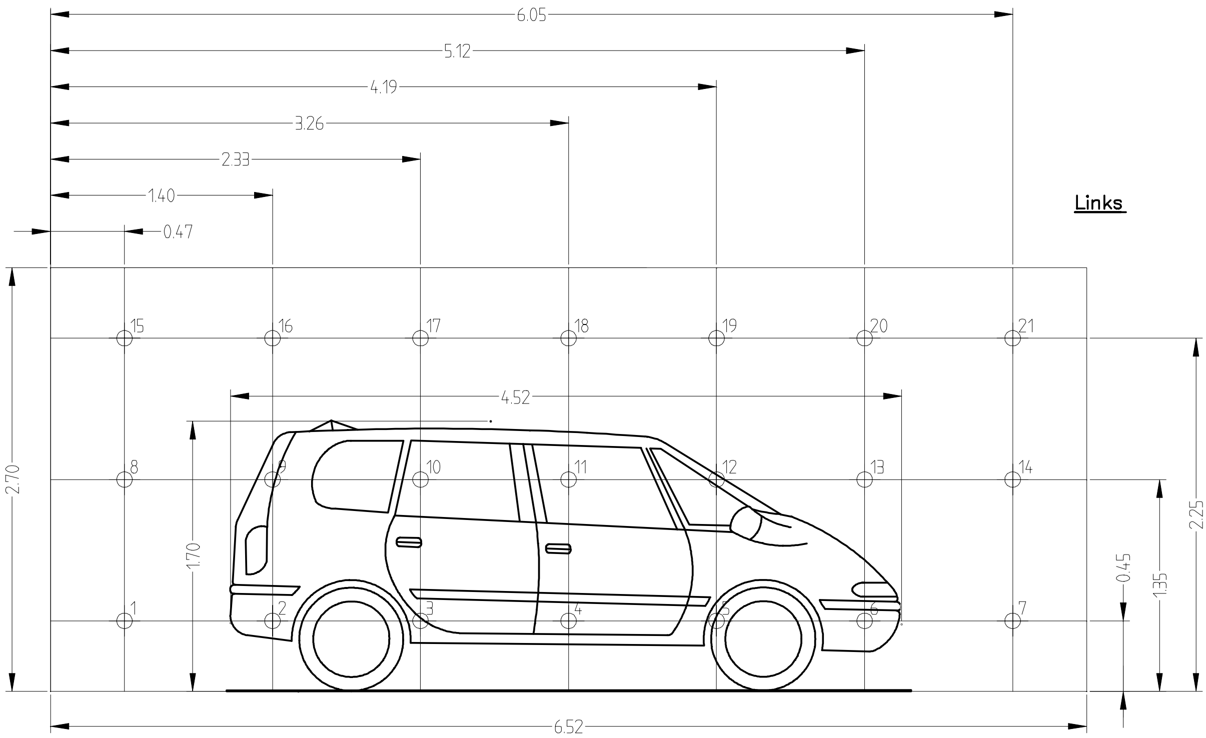

Fig. 5.17 Right measurement surface area side with measuring points

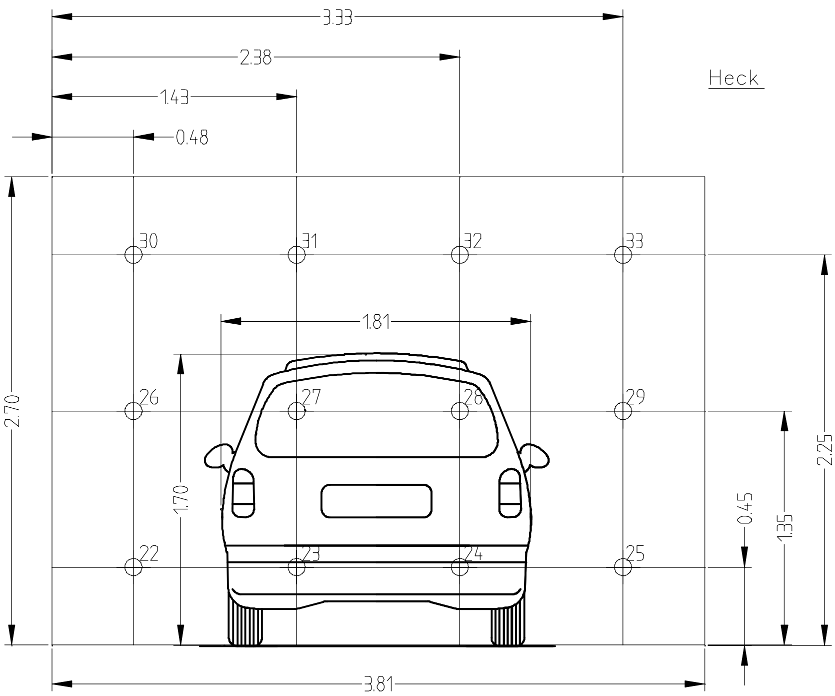

Fig. 5.18 Rear side with measuring points

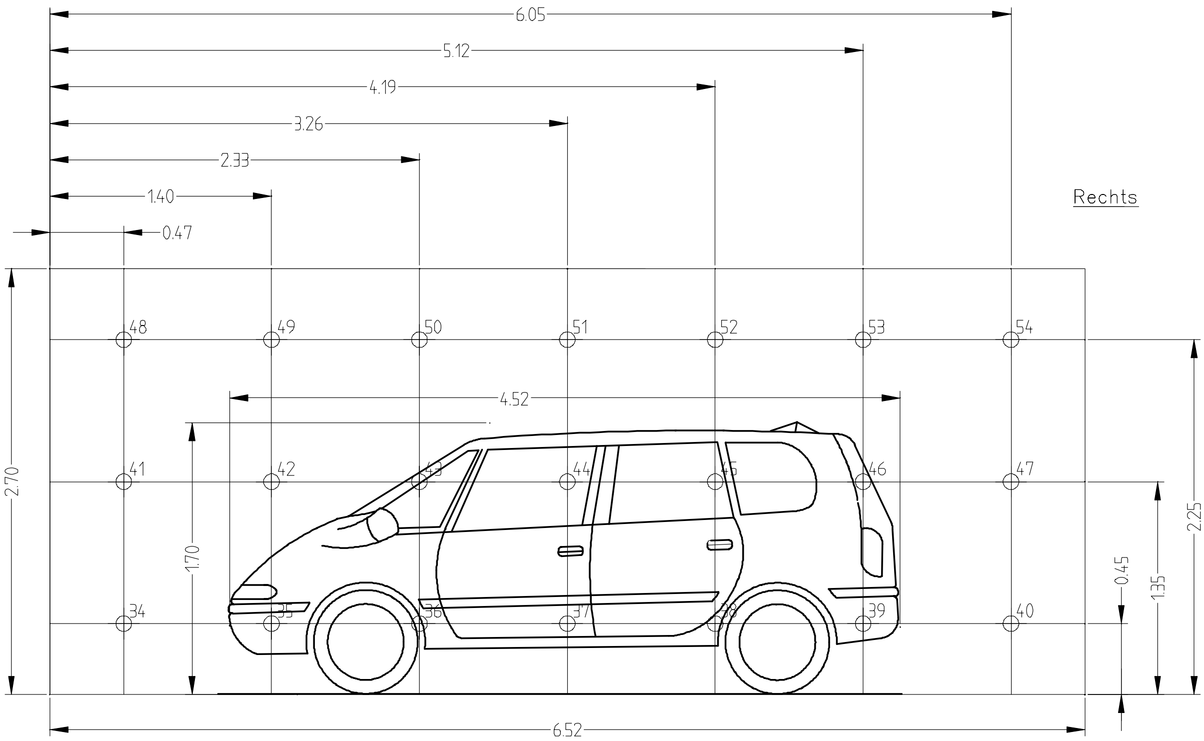

Fig. 5.19 Right measurement surface area side with measuring points

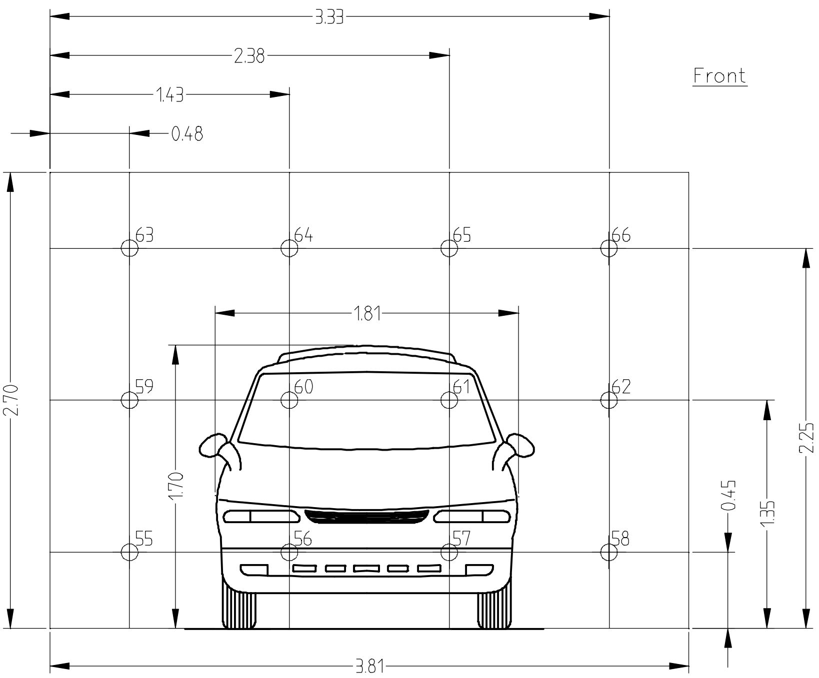

Fig. 5.20 Front side with measuring points

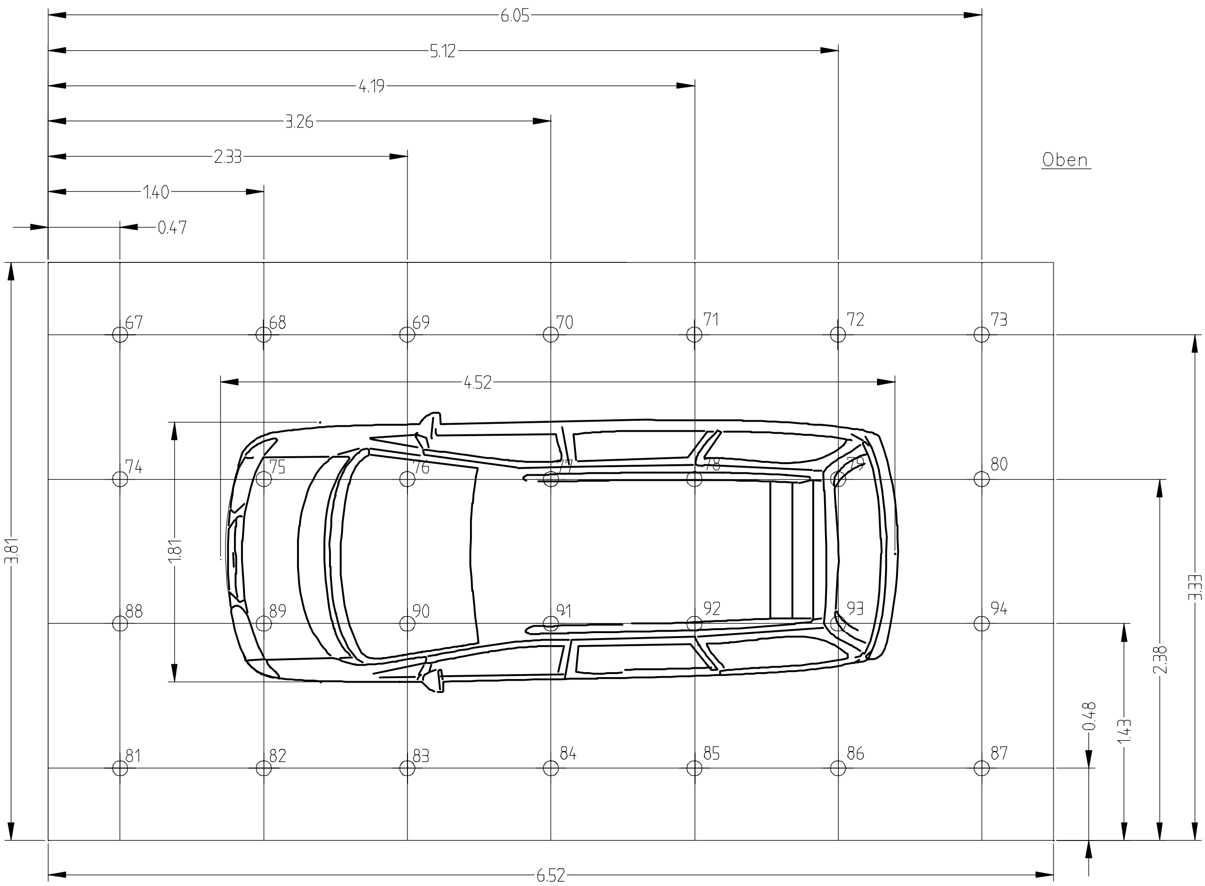

Fig. 5.21 Top side with measuring points

In the course of the investigation on this van as a model machine, the vehicle was placed in 6 different industrial halls – a frequency spectrum was determined at each measuring point of the cubic enveloping surface area when the built-in noise sound source was operated in each of these halls. This measurement took place in the two states 'non-directional emission' (windows all closed) as well as 'directional emission' (one window open on the left side).

These measurements were carried out to be able to assess the uncertainties in determining the emission sound pressure level according to the different standards of the ISO 11200 series.

Within the framework of the investigation described here, this raw data was used to be able to determine what margins of error result in determining the directivity index at any point or in determining the mean level on the measurement surface if the approximation strategies already mentioned are applied.

To achieve this, another evaluation was performed, described using the example of the measurement in Hall 1 in the following.

The starting point are the A-weighted sound pressure levels (not the spectrums) at all 94 measuring points in accordance with Tab. 5.1.

Tab. 5.1 Levels determined on measurement of the noise emission of the van in hall1

Point Nr.	omnidirectional	directional	Point Nr.	omnidirectional	directional
1	67.9	70.1	48	64.9	79.3
2	69.0	70.8	49	65.4	80.0
3	69.2	71.0	50	66.8	81.1
4	70.1	71.7	51	67.2	80.4
5	68.2	70.2	52	66.9	78.0
6	66.3	69.5	53	66.6	75.5
7	66.4	70.2	54	66.2	73.1
8	66.2	69.3	55	66.1	70.3
9	67.3	70.1	56	65.8	70.7
10	67.0	69.9	57	66.2	72.2
11	66.1	70.3	58	67.1	74.9
12	65.9	69.8	59	65.4	71.3
13	66.4	70.9	60	65.2	72.5
14	64.7	70.3	61	64.7	73.5
15	65.4	69.3	62	64.2	75.2
16	67.4	69.9	63	65.1	70.6
17	67.1	70.3	64	65.9	72.3
18	67.8	71.0	65	67.4	74.5
19	66.7	70.6	66	66.0	76.7
20	65.3	70.2	67	65.0	70.9
21	65.2	70.2	68	67.6	71.5
22	67.4	72.9	69	67.0	71.2
23	68.7	71.1	70	68.6	72.2
24	70.5	71.7	71	67.9	70.9
25	67.8	70.1	72	67.5	70.2
26	67.0	72.7	73	66.2	69.7
27	67.8	71.3	74	65.8	72.1
28	67.3	69.8	75	68.3	72.3
29	65.9	68.6	76	68.5	72.9
30	67.0	72.4	77	69.1	72.8
31	67.4	71.6	78	70.0	72.2
32	68.0	70.4	79	69.4	71.5
33	65.8	69.4	80	68.7	71.3
34	65.9	76.6	81	66.0	76.8
35	66.6	79.9	82	67.1	78.2
36	68.0	83.3	83	67.2	80.0
37	69.9	80.1	84	68.1	79.7
38	68.4	76.3	85	67.5	77.0
39	66.7	73.4	86	66.7	74.2
40	67.1	72.5	87	66.4	73.0
41	66.0	78.7	88	66.2	74.4
42	66.1	81.9	89	67.2	76.4
43	65.7	85.8	90	69.4	76.4
44	67.0	82.1	91	69.5	75.1
45	66.8	77.7	92	70.0	74.0
46	66.2	73.0	93	70.1	72.7
47	65.3	72.0	94	68.4	72.4

result	omnidirectional	directional
Mean level (energetic)	67.3	75.6
Mean level (arithmetic)	67.1	73.5
standard deviation	1.4	3.8

These values are now used to determine the mean level values for all 4 sides as well as for the top surface. This is done both with all the measuring points of this side of the cubic and – as approximate value – using only one or two measuring points in the side center. Tab. 5.2 shows this evaluation.

Tab. 5.2 Hall 1 mean level on the individual surfaces of the measurement surface area cubic

Side	Area m²	Points no.	Representative point	Omnidirectional		Directional	
				All points	Repr. point	All points	Repr. point
right	18.1	1 to 21	11	67.2	66.1	70.3	70.3
rear	10.4	22 to 33	27 and 28	67.7	67.6	71.2	70.6
left	18.1	34 to 54	44	66.8	67.0	79.7	82.1
front	10.4	55 to 66	60 and 61	65.8	64.9	73.4	73.0
top	25.3	67 to 94	77 and 91	68.1	69.3	74.6	74.1

Now the measurement surface level is determined according to different strategies and the resulting deviations from the real value are determined (Tab. 5.3).

Tab. 5.3 Table 10 Hall 1 – determining the margin of error for application of methods of approximation

Strategy		SPL in dB		Deviation in dB	
		Omnidir.	Directional	Omnidir.	Directional
0	True value (all 94 points)	67.3	75.6		
1a	Repr. points without top	66.5	77.1	-0.8	1.5
1b	Repr. points with top	67.2	76.6	-0.1	1.0
2a	Repr. Points area-weighted without top	66.5	77.8	-0.8	2.2
2b	Repr. Points area-weighted with top	67.6	77.0	0.3	1.4
3	Average on circumferencial path	66.2	76.9	-1.1	1.3

As expected, the deviations in the state 'non-directional emission' are the lowest. In the case of directional emission, the model machine has directivity indices DI between –10 dB and + 12 dB. This in turn is a very high value with regard to real machines. The deviations determined using only a few substitute measuring points lie essentially below 2 dB.

This is confirmed in the investigation with the data determined in 5 other halls. On the whole, the deviations remain in the range from 0 to 2 dB.

This means that the following can be stated in summary:

By selecting substitute measuring points in the side centers of the measurement surface area cubic or by means of integration on a surrounding path, the measurement surface level can be determined with a deviation from the real value that only exceeds the value of 2 dB in exceptional cases.

6 The grade of accuracy in determining the emission sound pressure level

6.1 Determining the emission sound pressure level without application of an environmental correction (ISO 11201)

6.1.1 Including the apparent directivity index DI'

According to ISO 11201, the emission sound pressure level used directly is the sound pressure level determined at the specified position or workplace. Due to the restriction of the method to rooms in which the environmental correction K_2 related to sound power level is less than or equal to 2 dB, it is assumed that the environmental correction K_3 within the framework of the grade 2 assigned to this method can be neglected.

As described in section 6, the following margins of error in relation to the environmental influence can be accepted in the individual grades of accuracy:

- grade 1 0.3 dB
- grade 2 1.5 dB
- grade 3 3.0 dB

If K_3 is not applied, its value corresponds exactly to the margin of error for determining the emission sound pressure level.

The relationship

$$DI' = -10 \cdot \lg\left(\frac{1-10^{-0.1 \cdot K_3}}{1-10^{-0.1 \cdot K_2}}\right) dB \qquad (28)$$

is now shown as a diagram and the curves for K_3 = 1.5 dB and for K_3 = 3 dB are drawn.

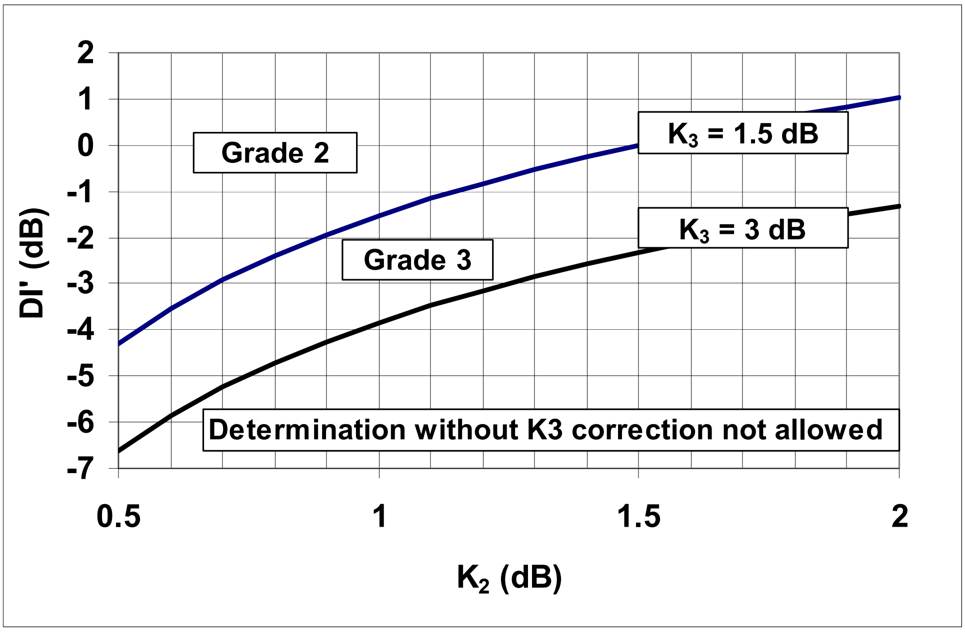

Fig. 6.1 Delimitation of the areas with margins of error up to 1.5 dB or 3 dB when an environmental correction is not applied

For a machine with the given apparent (i.e. measured in the room) directivity index DI', it is now easy to decide which grade the method belongs to if the environmental correction K_3 is not applied.

As expected, the result for non-directional emission (DI' = 0 dB) in a room with K_2 = 1.5 dB is also a K_3 = 1.5 dB – the corresponding point lies exactly on the upper curve. It is only a problem if there is a negative directivity index DI' – now a smaller K_2 or an acoustically more favorable room is necessary to maintain K_3 = 1.5 dB or if K_3 is neglected to keep the margin of error caused at 1.5 dB.

If the margin of error becomes greater than 1.5 dB, the result of determining the value no longer corresponds to grade 2. It is to be assigned to grade 3 or - if the neglected K_3 is greater than 3 dB – determining the emission sound pressure level according to this method is no longer possible at all.

6.1.2 Including the simplified apparent directivity index DI'_{approx}

Measurement of the directivity index DI' requires, as has been shown, determining both the sound pressure level at the specified position or at the workplace as well as determining the mean sound pressure level on an enveloping surface area surrounding the source.

As a rule, the time effort for determining this measurement surface level is many times greater than for determining the level at the workplace itself. If it is taken into account that with all of this time effort only the environmental correction K_3 is ascertained and that in many cases this is only 1 to 2 dB, the requirement for a simplified determination of this K_3 correction becomes understandable.

The simplified determination means that the directivity index that applies to the workplace point or the mean sound pressure level on the measurement surface is only determined approximately. In accordance with the information in the last chapter, this can take place exclusively by measurement at the 4 side centers of the measurement surface area cubic and averaging or continuous integration on moving the microphone on a closed surrounding path.

As was also seen in the last section, the implied margin of error for the method of approximation remains essentially below 2 dB.

According to the strategy proposed here, this margin of error is taken into account in determining the uncertainty of the method.

The starting point is the relationship (28) derived in section 5.4.2, whereby the method of approximation means, however, that an additional uncertainty of 2 dB is to be taken into account.

In the worst case, this means that in spite of determining DI'_{approx} at for example – 2 dB the actual directivity index DI' could be – 4 dB and the corresponding K_3 would therefore be greater.

This takes place by introducing the relationship

$$DI'_{approx} = DI' + 2\ dB \qquad (28b)$$

This results in

$$DI'_{approx} = (-10 \cdot \lg\left(\frac{1-10^{-0.1 \cdot K_3}}{1-10^{-0.1 \cdot K_2}}\right) + 2)\ dB \qquad (28c)$$

In the calculation based on (28), it is assumed for the sake of certainty (in a manner of speaking) that the directivity index could also be 2 dB more negative than determined approximately. The result of application of the method of approximation is therefore more frequently classified in grade 3, although the actual deviation means it would correspond to grade 2. The other way around, there is great certainty that a result allocated to grade 2 does not deviate from the true value to the extent that it really would have had to be allocated to grade 3.

(28c) results in

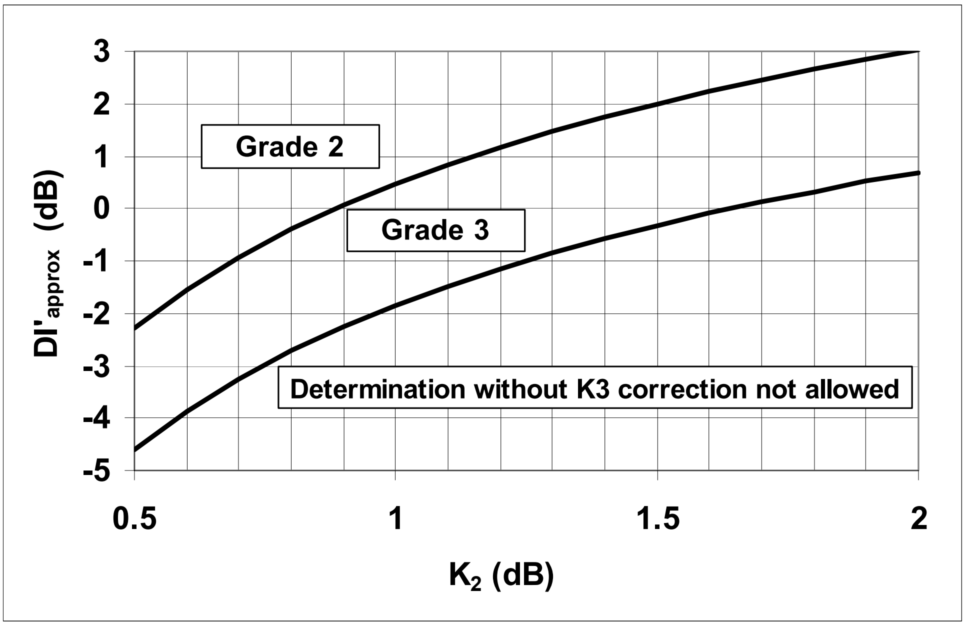

Fig. 6.2 Delimitation of the areas with margins of error up to 1.5 dB or 3 dB if an environmental correction is not applied – the additional uncertainty of 2 dB due to the approximate determination of the directivity index is integrated

Fig. 6.2 permits a simple assessment of the grade achieved. However, it also shows that determining the emission sound pressure level according to this strategy 'on the safe side' without application of an environmental correction is only possible in acoustically favorable rooms with a small K_2.

Even in a room with a K_2 of 2 dB, this measurement no longer corresponds to the requirements if the method of approximation has been used to determine omni-directional emission – the point with K_2 = 2 dB and D'_{approx} = 0 dB does not lie within the permitted range. This is simply the consequence of the fact that the directivity index could also be – 2 dB – it has only been determined approximately with 4 measuring points.

6.2 Determining the emission sound pressure level using the environmental correction K_3 (ISO 11202 and ISO 11204)

6.2.1 Including the apparent directivity index DI'

Once K_3 has been determined, it can also be subtracted from the sound pressure level ascertained at the specified position or at the workplace and therefore applied.

In this case, the upper limits for the permitted K_3 for the individual grades are

- 2 dB grade 2
- 7 dB grade 3

The method is the same as that described above. On the basis of the relationship (28) or (28b) and (28c), diagrams DI(K_2) are created in which the validity ranges for the individual grades are delimited using the curves K_3 = const. The parameter values now used as the basis are the above-mentioned values 2 dB and 7 dB.

With equation (28), this leads to Fig. 6.3.

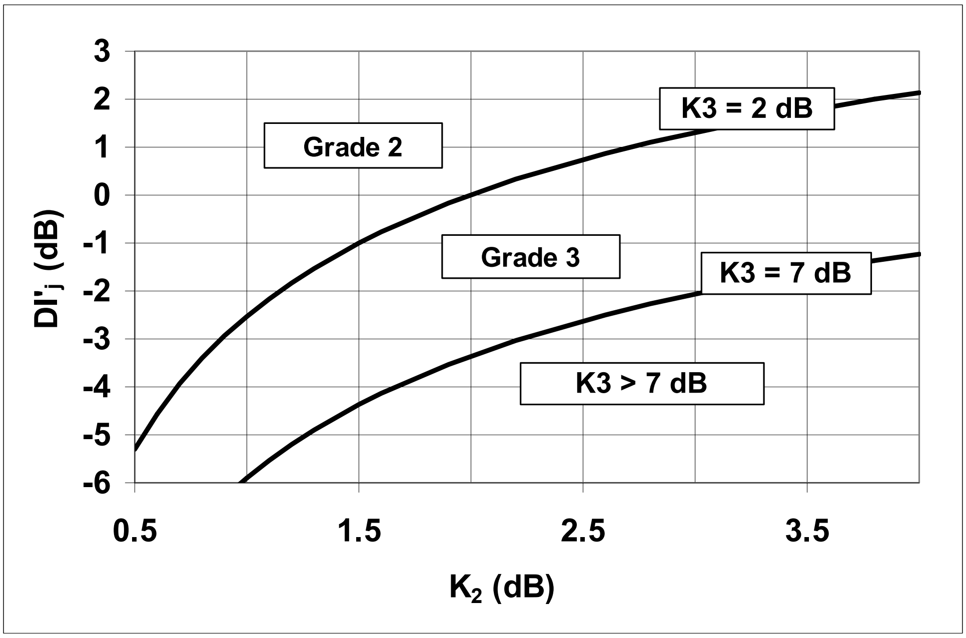

Fig. 6.3 Delimitation of the ranges for grades 2 and 3 with application of the environmental correction K_3

As expected, in a room with K_2 = 2 dB and with non-directional emission with DI' = 0 dB, the diagram shows a point on the curve for K_3 = 2 dB.

The application Fig. assumes that DI' is known exactly or that it has been determined taking account of a measurement surface that envelopes the entire source.

6.2.2 Including the simplified apparent directivity index DI'_{approx}

For the reasons stated above, it serves the purpose to determine the directivity index or mean level on the measurement surface approximately. In this case, it is assumed in turn that the margin of error remains below a limit of 2 dB and therefore relationship (28c) can be presupposed.

This leads to Fig. 6.4.

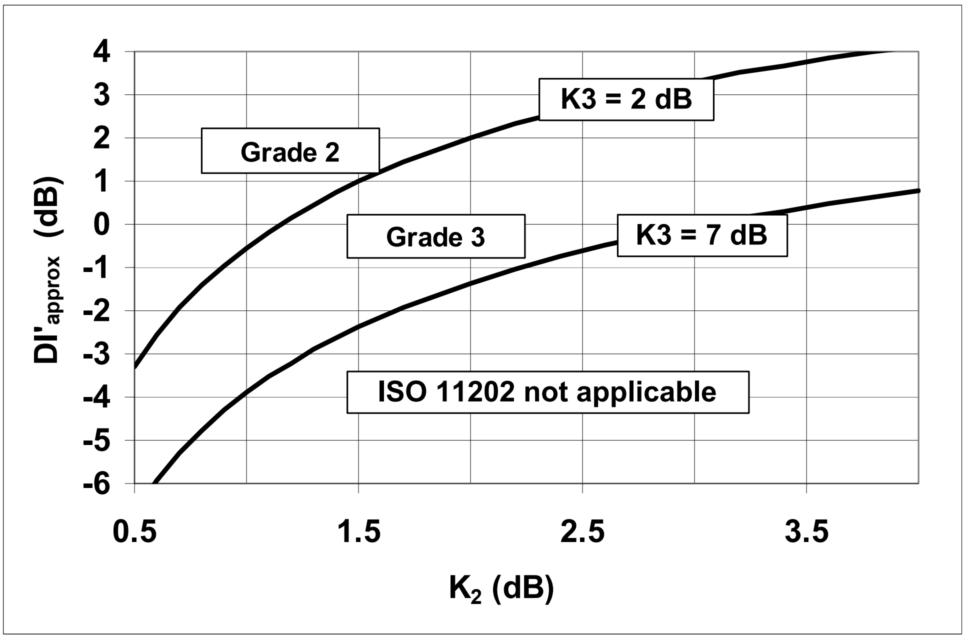

Fig. 6.4 Delimitation of the ranges for grades 2 and 3 with application of the environmental correction K_3 – an uncertainty of 2 dB due to the approximate determination of the directivity index is integrated

The approximate determination of the apparent directivity index is therefore - even in the case of omnidirectional emitting machines - only possible in rooms up to a K_2 of approx. 3 dB – if the room is acoustically less favorable, the machine is larger or the apparent directivity index is negative, this method of approximation cannot be used. The directivity index is then to be determined including measuring points on the entire enveloping surface area according to ISO 11204.

7 Determining the emission sound pressure level with known difference L_W - L_p

The above-mentioned relationships are the basis for a planned revision of the ISO 11201, 11202 and 11204 series of standards.

In the longer term, however, even more methods could be used to simplify measurement of the emission sound pressure level and in particular to exploit existing prior knowledge regarding the typical emission for a type of machine to reduce the measurement time effort.

A good basis for this is provided by the relationships stated in section 5.4.1

$$K_3 = 10 \cdot \lg\left(1 + \frac{4 \cdot A_0}{A} \cdot 10^{0.1 \cdot L_{W-p}}\right) dB \qquad (14)$$

or

$$K_3 = 10 \cdot \lg\left[1 + \frac{S_0}{S} \cdot \left(10^{0,1 \cdot K_2} - 1\right) \cdot 10^{0,1 \cdot L_{W-p}}\right] dB \qquad (15)$$

The numerical difference between sound power level and emission sound pressure level

$$L_{W-p} = L_W - L_p$$

or the value range of this difference is well known after a number of years' experience in measuring a type of machine, which means it can be taken into account as prior knowledge.

The relationship (14) is shown in Fig. 7.1. If for a machine type a typical value L_{W-p} is known, all that now needs to be determined is the equivalent absorption area of the room, e.g. using a measurement of the reverberation time. The calculated value of the equivalent absorption area A allows to read the point related environmental correction K_3 from Fig. 7.1.

In determining the grade according to this proposal, however, the fact should be taken into account that the actual value L_{W-p} of this special machine has not been used but rather the mean value for an entire machine group. To this end, a value $K_{3,max}$ is set with a certain level of confidence - e.g. 95 % - from different possible values L_{W-p}.

This results in

- Grade 2 with K3,max ≤ 2 dB
- Grade 3 with 2 dB ‹ K3,max ≤ 7 dB

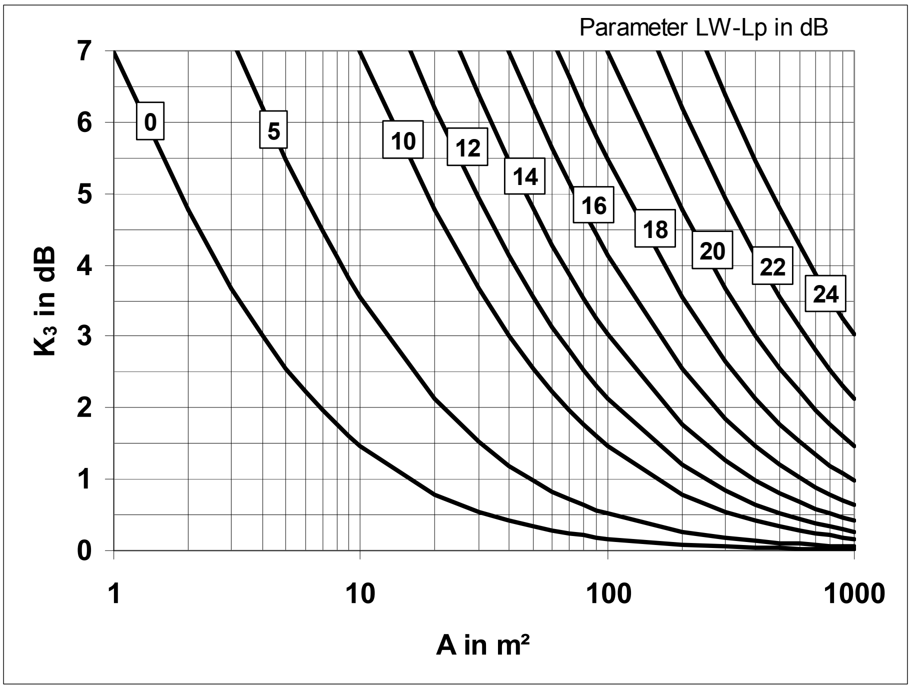

Fig. 7.1 Determining the environmental correction K_3 from the parameter difference L_{W-p}

Depending on the value of this $L_{W-p,max}$ to be assumed as upper limit and A, the applicable grade can be taken from Fig. 7.2.

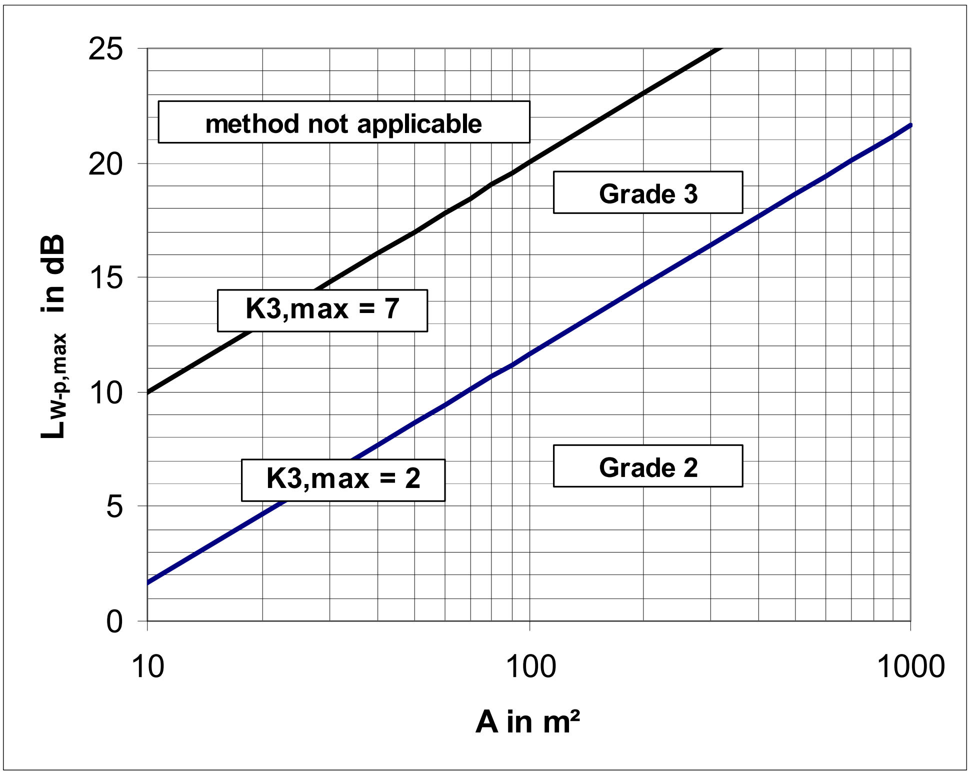

Fig. 7.2 For determining the grade with the precondition that there is a machine-specific interval of the level difference L_{W-p}

Application example, molding machine:

The molding machines in foundries with emission values reported in /19/ are investigated. The following table lists the emission sound pressure levels and sound power levels as well as the numerical difference between these two values for 17 different machines. The mean value of this difference is 19 dB; the highest value is 23 dB.

Tab. 7.1 Emission parameters and their difference for molding machines in foundries

No.	Typ	L_p dB(A)	L_W dB(A)	L_{W-p} dB
1	Suction-	81.3	102.2	20.9
2	Suction-	82.9	102.0	19.1
3	Suction-	82.6	102.7	20.1
4	Suction-	79.3	102.0	22.7
5	Air-impulse	92.0	110.2	18.2
6	Air-impulse	90.5	110.0	19.5
7	Air-impulse	83.0	104.5	21.5
8	Air-impulse	84.0	102.4	18.4
9	Air-current	81.5	99.3	17.8
10	Air-current	80.6	99.4	18.8
11	Air-current	81.6	98.6	17.0
12	Air-current	82.4	100.1	17.7
13	Shoot-press	81.2	98.2	17.0
14	Shoot-press	84.5	105.5	21.0
15	Shoot-press	85.9	109.0	23.1
16	Shoot-press	96.9	110.0	13.1
17	Shoot-press	90.4	107.0	16.6
	Mean			19.0
	Standard deviation			2.5

As too few single values for the molding machines that work according to various principles, the machine type 'molding machine' will be assumed in what follows, and thus a standard deviation of 2.5 dB.

Assuming a confidence level of 95 % for falling short of the assumed value, this results in

$$L_{W-p,max} = (19 + 1.645 \times 2.5)\ dB = 23.1\ dB \qquad (39)$$

According to this proposal, the two values

$$\overline{L}_{W-p} = 19\ dB \text{ and}$$

$$L_{W-p,\max} = 23\ dB$$

will be specified and published in the noise measurement standard or in the noise section of the safety standard.

In order to simplify the direct implementation, (14) could be used to enter the two curves for mean value 19 dB and maximum value 23 dB in a diagram corresponding to Fig. 7.3.

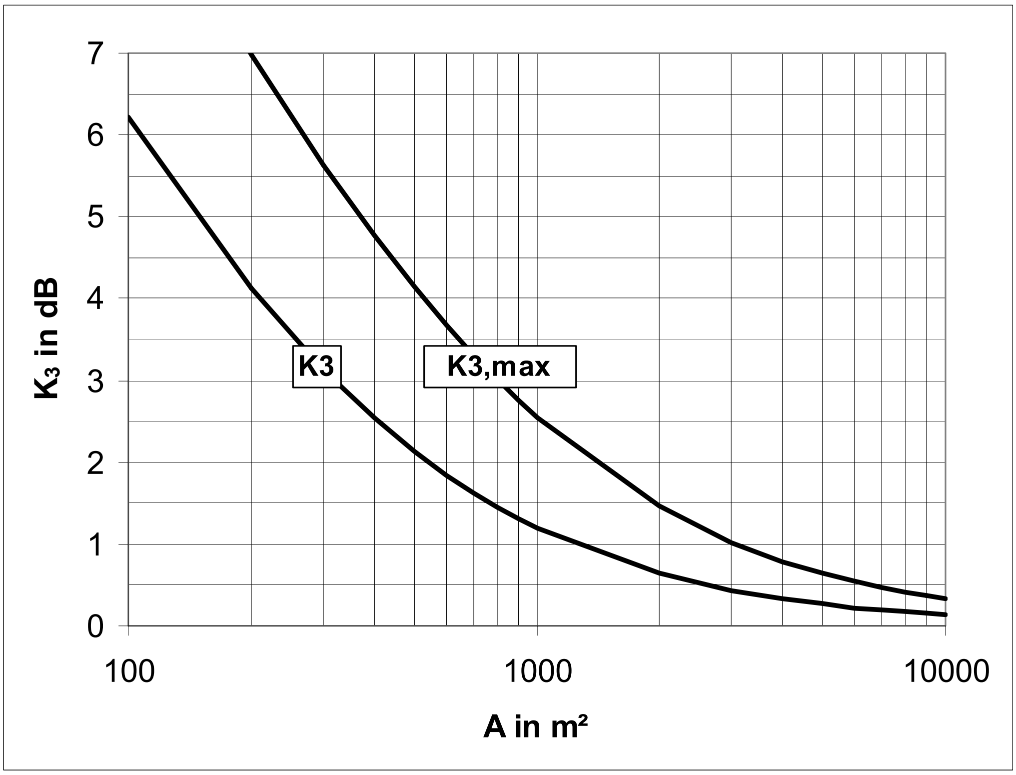

Fig. 7.3 Curves for determining the environmental correction and grade when determining the emission sound pressure level on molding machines

If the emission sound pressure level of a certain molding machine XY is to be determined in a concrete case, only two measurements are required. In the first step, the equivalent absorption area A of the room in which the machine is operated is ascertained using one of the known methods. In the second step, the sound pressure level at the workplace is measured, taking account of the measurement specification with regard to operating conditions.

With the determined equivalent absorption area A, the curve designated with K_3 of Fig. 7.3 results directly in the environmental correction to be applied, and by subtracting the same from the determined sound pressure level at the workplace the target emission sound pressure level results. Furthermore, the equivalent absorption area A and the upper curve of the diagram determines a value $K_{3,max}$ as well as the grade of the result. Here, the following applies

Grade 2 for $K_{3,max} \leq 2$ dB
Grade 3 for 2 dB < $K_{3,max} \leq 7$ dB

How to proceed if $K_{3,max}$ is greater than 7 dB should also be regulated in the measurement standard or in the noise section of the safety standard. According to our proposal, this should be specified every time the noise parameter is stated.

Example:

In a foundry hall, the equivalent absorption area is set at 300 m² and the sound pressure level at the workplace at 85 dB(A) in the course of determining the emission sound pressure level of a molding machine.

Fig. 7.3 results in K_3 at 3 dB and $K_{3,max}$ at 5 to 6 dB. This means the emission sound pressure level is

L_p = (85 – 3) dB = 82 dB

and the measurement is to be allocated to grade 3.

Application example, industrial sewing machine:

Another example concerns the group of industrial sewing machines. The dimensions of these machines – dimensions of a large portion of this machine group – are approximately the same.

Fig. 7.4 Typical industrial sewing machine with concealed-body drive

This is the first requirement that the differences L_{W-p} are not extremely different and therefore the mean value can be assumed for the entire group. Another positive requirement for successful application of the method described here – derivation of the environmental correction from a difference L_{W-p} that is uniform for the machine group - is the presence of a dominant main noise source and the smallest possible distance between this and the specified workplace.

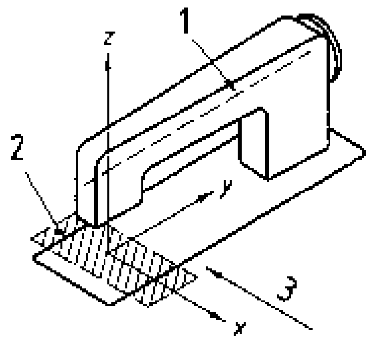

Fig. 7.5 Coordinate system for specification of the workplace

According to ISO 10821 /20/, the measuring point for determining the emission sound pressure level at the workplace is located at the coordinates (400 mm, 0 mm, 300 mm) of the coordinate system shown in Fig. 7.5 and is therefore at a distance of 0.5 m from the needle insertion point. If this point is viewed as the main sound source, the geometry of the sound propagation from the source to the workplace point is largely uniform and no extremely different values are expected for the level difference L_{W-p}.

This can now be verified using parameters determined earlier for these machines. Tab. 7.2 lists the emission values for a number of industrial sewing machines as well as the level differences stated. Their mean value is 8.1 dB – their variance features a standard deviation of 1.6 dB.

Tab. 7.2 Emission parameters of industrial sewing machines (based on /19/)

Type of machine	U	L_W	L_p	L_{W-p}
	1/min	dB(A)	dB(A)	dB
Single blindstitch hemming machine	2300	81	73	8
Single thread blindstitch belt loop machine	3000	93	84	9
Single thread blindstitch sewing system	2500	85	78	7
Flap pique machine	2800	81	73	8
Single thread point clamp machine	1200	84	75	9
Double thread overedging machine with differential	1900	84	76	8
Fur sewing machine	2800	86	78	8
Double thread overedging machine	1800	82	73	9
Single thread blindstitch hemming machine	1800	87	76	11
Single thread double blindstitch hemming machine	2200	85	77	8
Single thread double blindstitch hemming machine	2000	84	75	9
Industrial blindstitch roll-pitating machine	3300	85	77	8
Single thread chainstitch edge reaming and stapling machine	2000	91	84	7
High performance fur sewing machine	2300	90	80	10
High performance high speed fur sewing machine	3200	90	80	10
Double thread piling machine	1300	89	83	6
Double thread double hollow edge machine	1300	83	78	5
Double thread blindstitch piling machine	1350	89	81	8
Double thread hem piling machine	1300	88	82	6
Double thread lining-pile machine	1300	86	80	6
Double thread cuff lining-pile machine	1300	86	79	7
High performance single thread blindstitch machine	2500	87	76	11
Mean				8.1
Standard deviation				1.6

Described in the same way as in the case of the molding machines, this results in

$L_{W\text{-}p,max}$ = (8 + 1,645 x 1.6) dB = 10.6 dB (40)

According to this proposal, the two values

$\overline{L}_{W-p} = 8\ dB$ and

$L_{W-p,\max} = 11\,dB$

will be specified and published in the noise measurement standard or in the noise section of the ISO 10821 safety standard. In order to simplify the direct implementation, (14) could in turn be used to enter the two curves for mean value 8 dB and maximum value 11 dB in a diagram corresponding to Fig. 7.6.

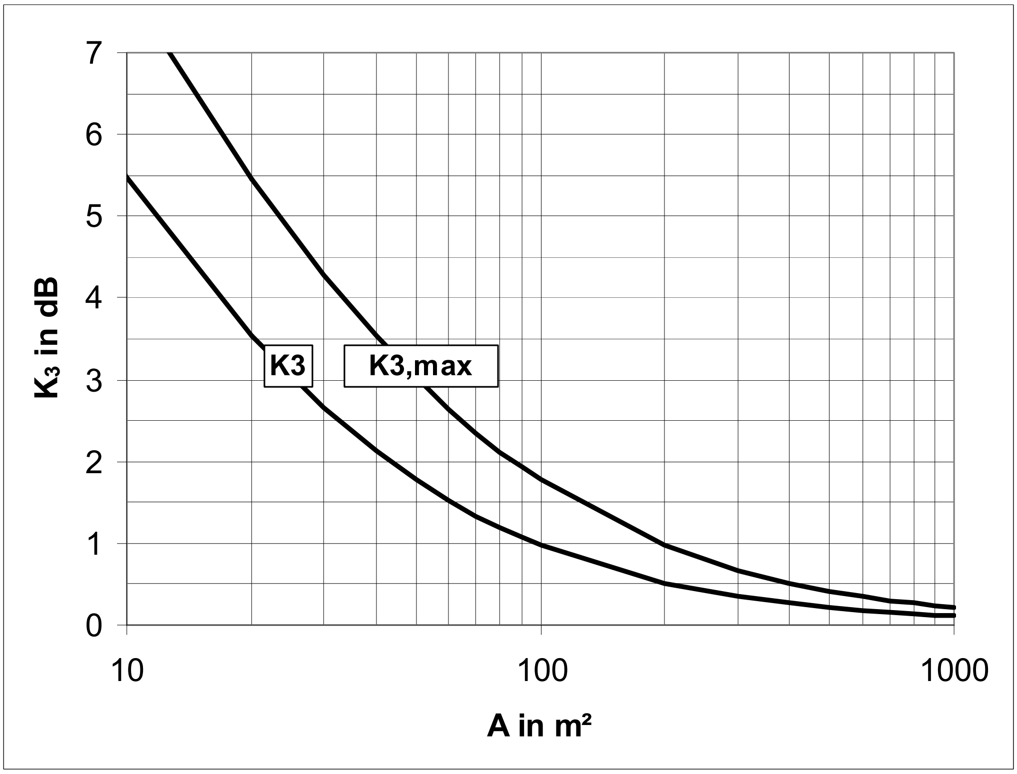

Fig. 7.6 Curves for determining the environmental correction and grade when determining the emission sound pressure level for industrial sewing machines (fictional case of machine-specific specification)

On application of this diagram, measurement of the emission sound pressure level is in turn extremely simple. If, for example, in a sewing room the equivalent absorption area is set at 100 m² and the sound pressure level at the workplace of the machine at 78 dB(A), the lower curve in Fig. 7.6 results in a K_3 of 1 dB and therefore an emission sound pressure level of 77 dB(A) and the upper curve results in assignment to grade 2.

In general, the method described here is extremely well suited in order to carry out sound measurements exclusively at the workplace when determining the emission sound pressure level and to be able to limit the required number of measurements to a minimum. Curve $K_{3,max}$ will differ from curve K_3 all the less the smaller the standard deviation or variance of the level difference L_{W-p} is for a machine type. This is of interest in order not to have to allocate every measurement – even if the determined K_3 is small – to grade 3. If the variance is too great, it should be checked whether forming groups within the machine type can reduce the variance with regard to these groups.

8 ISO 11201 – existing deficiencies and proposal for improvement

8.1 Essential content of the existing standard

The measurement according to the existing ISO 11201 corresponds to grade 2. The standard deviation of reproducibility should be a maximum of 2.5 dB. The method is only permitted in environments in which the value of the environmental correction K_2 referring to the entire measurement surface does not exceed the value 2 dB.
The environmental correction K_3 is not used according to ISO 11201 – i.e. with the conditions stated.

The range of application of this standard is therefore determining the emission sound pressure level in cases in which the environmental influence is so low that it can be neglected within the framework of the deviations compatible with the grade. The sound pressure level measured at the workplace or at the specified position is then used directly as the emission sound pressure level without any other correction.

This method is of interest if the measurement is carried out in large rooms and/or rooms equipped with absorption or if small machines are involved. It is easy to carry out, as only the direct sound pressure level measurement at the workplace of the machine is required.

8.2 Deficiencies in the existing standard

According to ISO 11201, in spite of neglecting an environmental correction, the margin of error this causes should be adequately limited in that the application is only permitted if the environmental correction K_2 referring to the entire measurement surface remains below 2 dB.

This is unacceptable because the level increase at the workplace caused by the room depends not only on the acoustic room properties and size of the machine or measurement surface, rather to a considerable degree on the directivity index of the emission. Chapter 2.4 both explains this qualitatively and proves it quantitatively on the basis of equations (16) and (17).

As an example for the failure of the existing ISO 11201, Example 1 – a machine with 1 m dimensions - from section 5.2 will be examined. If the measuring point opposite the main sound source is regarded as the workplace, an emission sound pressure level of 72 dB(A) results.

This machine is now placed in an industrial hall with an equivalent absorption area of 225 m². For the 1 m measurement surface, this value leads to a K_2 of exactly 2 dB. This means the environmental correction K_3 according to ISO 11201 can be neglected.

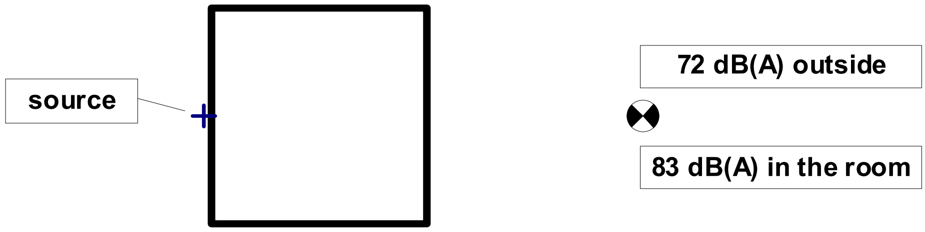

Fig. 8.1 The sound pressure level at the workplace outdoors and in the room with K_2 = 2 dB

Both the simulation calculation and the approximate calculation according to statistical theory show that in this case a level increase to 83 dB can be expected – the actual environmental correction K_3 would therefore be 11 dB. It is obvious that that the directivity of the emission must definitely be taken into account in determining application limits for ISO 11201.

8.3 Proposal for a revision or new version

The following section contains a brief description of the essential content of a revised standard. The expression 'ISO 112XX new' will be used as a short form for 'Revision of the ISO 112XX in accordance with the proposal'. All the specifications for the machine to be tested, the installation and operating conditions as well as for determining the sound pressure level at the workplace or sound pressure level in a workplace area are identical in ISO 11201, 202 and –204 new.

8.3.1 Measurement in the room according to grade 1

ISO 11201 Part 1
The measurement takes place in a room that corresponds to the requirements of ISO 3745 Annex A.

The level of extraneous noise must be at least 10 dB lower than the level at a sound source in operation.

The determined A-weighted sound pressure level at the specified position is the emission sound pressure level of the machine.

The emission sound pressure level determined at the specified position is related to the conditions

$B_0 = 1.01325\ 10^5$ Pa
$T_N = 296.15$ K

(B static air pressure, T temperature). If the actual values deviate from this during measurement, the value L_p determined at air pressure B and temperature T is to be related using

$$L_{p,N} = L_p - 25\,\lg\left(\frac{B}{B_N}\right)dB + 20\,\lg\left(\frac{T}{T_N}\right)dB \qquad (41)$$

to the standard conditions.

8.3.2 Measurement in the free sound field according to grade 1

ISO 11201 Part 2
The measurement takes place outdoors on a reflecting surface area.

No reflecting objects may be located so close to the measurement arrangement that a level increase relevant within the framework of grade 1 (< 0.3 dB) results.

Within the sense of this standard, objects are defined as reflecting if the degree of absorption of their surface is less than 0.5 and if they are geometrically in a reflection condition with an acoustically smooth surface or if they have a diffusely reflecting surface structure.

Reflecting objects must be sufficiently small or sufficiently far away.

In the case of free sound propagation between the sound source and immission point, this is ensured if individual reflecting surface areas are at a distance to the measurement point and sound source that is at least twice the distance between the measuring point and machine point that is furthest away. The distance from reflecting objects to the measurement point and machine should not be less than 10 m.

In the case of more complex propagation conditions, e.g. with sources screened from the specified position or several reflection surface areas surrounding the source and measurement point, it should be checked in individual cases whether and to what degree reflected proportions of sound can increase the level.

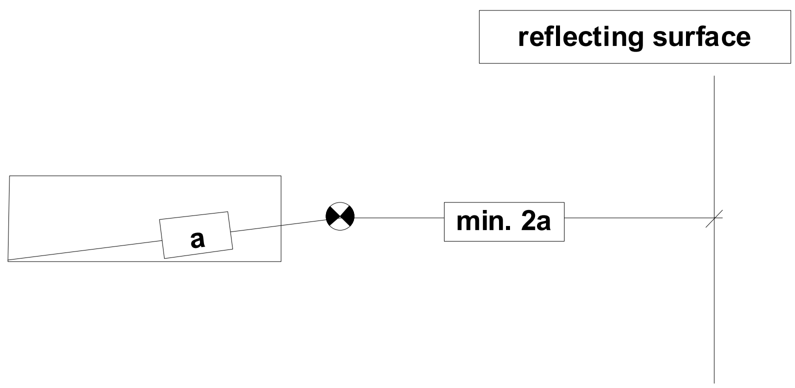

Fig. 8.2 Minimum distance of reflecting surfaces

8.3.3 Measurement in the room according to grades 2 or 3

REMARK: This method is described here, but was in the meantime removed from the proposal for a short term revision of ISO 11201.

ISO 11201 Part 3

Measurement takes place in rooms with an influence that is negligible within the framework of grades 2 and 3. Whether this influence of the room is negligible and which grade the result is to be allocated to is assessed in a two-stage process. This includes available knowledge of the machine emission and minimizes the measurement time effort.

- Determining the sound pressure level L'_p at the workplace
  This is determined taking account of any machine-specific specifications with regard to installation and operating conditions.
  Result -> L'_p in dB(A)

- Determining the environmental correction K_2 related to a fictional cubic measurement surface S

  This measurement surface S is to be selected preferably in such a way that the specified workplace is located on it. If the specified workplace is at a greater distance to the machine than 1 m, a measurement surface at a distance of 1 m is to be selected.
  Result -> K_2 in dB

- Determining the grade and emission sound pressure level L_p

  a. Assessment of the emission characteristics

     The assessment involves determining whether the sound pressure level at the workplace L'_p could be less than the mean sound pressure level $\overline{L}'_p$ on the measurement surface S. This is the case if
     ⇒ the major sound source is screened from the workplace (e.g. main emission at the back of the machine)
     ⇒ fewer noise-intensive sources are arranged at the side facing the workplace that on other sides
     ⇒ the workplace is at a greater distance from the machine than measurement surface S
     ⇒ there is a sound emission directed away from the workplace for other reasons

     In this case, the grade is determined according to c). If the emission is non-directional or the sound pressure level at the workplace L'_p is greater than the mean sound pressure level $\overline{L}'_p$ on the measurement surface S, the grade is determined according to b).

     An environmental correction K_3 is not applied according to this standard. The emission sound pressure level results from

$L_p = L'_p$

b. Determining the grade in the case of omnidirectional emission or emission directed towards the workplace (positive directivity index at the workplace)

Depending on the value of K_2, the following grade results:

$K_2 \leq 0.5$ dB	grade 2
0.5 dB $< K_2 \leq$ 1.0 dB	grade 3
1.0 dB $< K_2$	more exact determination required according to step c)

(This assignment results from the 'worst case' assumption that the actual apparent directivity index present could be 2 dB).

c. Determining the grade in the case of emission directed away from the workplace (level minimum or negative directivity index at the workplace)

The sound pressure levels are measured under operating conditions that comply with the standard in front of the side centers (points P1 to P4) at distance d (d is preferably 1 m) and the energetic mean value $\overline{L}'$ is calculated.

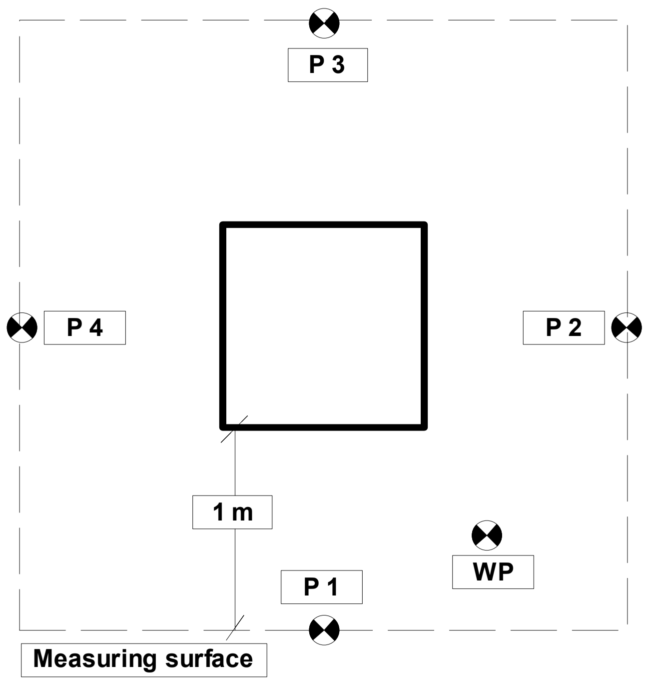

Fig. 8.3 Measuring points for determining the emission sound pressure level according to Part 3

$\overline{L}'$ can also be determined by continuous movement of the microphone at constant speed on a path surrounding the machine at a distance of 1 m with sliding integration.

This results in the apparent and approximately determined directivity index at the workplace for

$$DI'_{approx} = L'_p - \overline{L}'_{approx} \qquad (38)$$

With DI'_{approx} according to (38) and K_2 according to (6), the grade results from Fig. 8.4.

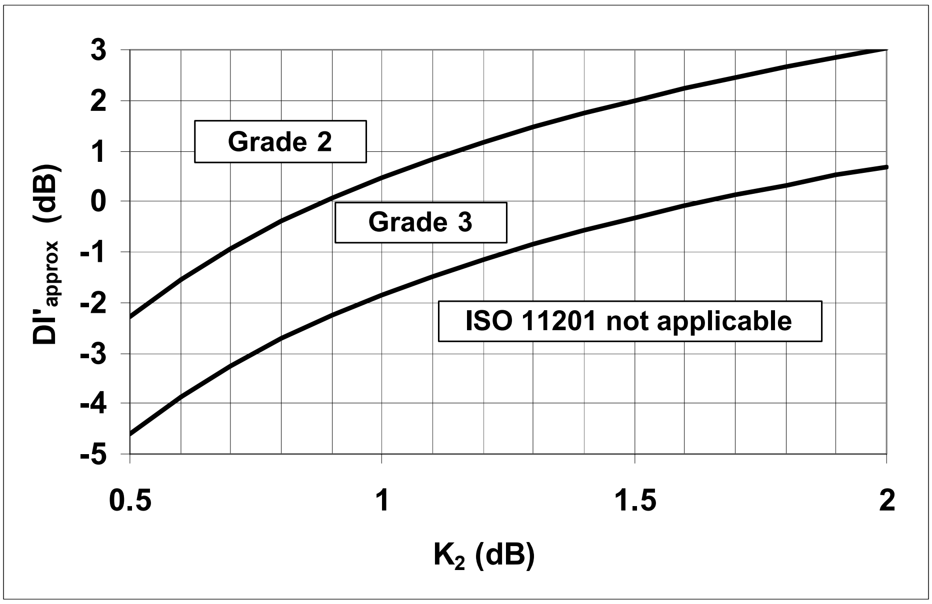

Fig. 8.4 Determination of the grade with environmental influence neglected

(The estimate according to Fig. 8.4 results from the 'worst case' assumption that the actual apparent directivity index present is 2 dB less than that which is approximately determined could be).

8.4 Application example

In the case of the machine described above with one-sided point source (Fig. 8.3), a sound pressure level at the workplace of 83 dB(A)resulted in the room with an equivalent absorption area of 225 m². Although the 'true' emissions sound pressure level is 72 dB(A), neglecting the K_3 correction would have been possible with the existing ISO 11201:1996.

For application of the ISO 11201:200x proposed here, the two workplaces AP 1 – facing the source – and AP 2 – facing away from the source – are examined.

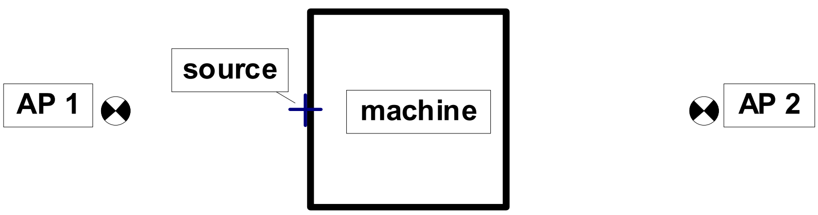

Fig. 8.5 Simple machine 1 m x 1 m x 1 m with one-sided point source

The simulation calculation leads to the sound pressure levels stated in Fig. 8.6 on the 4 sides.

We will now examine the case that only the sound pressure levels present in the room have been determined by measurement and then the emission sound pressure level related to the free sound field at the workplaces AP1 and AP2 by application of ISO 11201:200x Part 2.

The sound pressure levels at the 4 sides in the room result in a mean value of 87.3 dB. This means the directivity index DI'_{approx} is

4.6 dB at AP 1
-4.4 dB at AP 2

According to this ISO 11201:new, the grade results from Fig. 8.4. This results for

AP 1 – grade 2 – L_p = 91.9 dB
AP 2 – determination according to this standard not possible

This is an acceptable result – the emission sound pressure level for AP 1 ascertained in this way lies 0.6 dB above the true value and is therefore compatible with qualification by grade 2. In the case of AP 2 with a true influence of the room of 11 dB, on the other hand, neglecting an environmental correction not would be permissible at all – this is also recognized correctly according to this method.

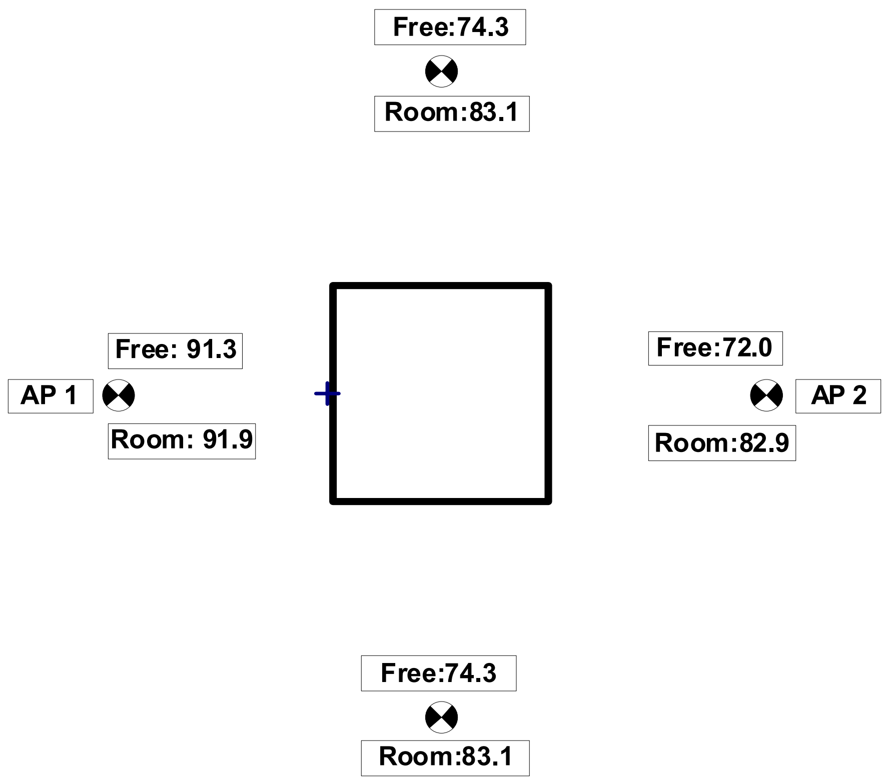

Fig. 8.6 Levels at four sides with measurement in the free sound field and in the room with 225 m² absorption area (determined by simulation calculation)

9 ISO 11202 – existing deficiencies and proposal for improvement

9.1 Essential content of the existing standard

The result obtained using this method is allocated to grade 3. The environmental correction is determined approximately and also applied.

The approximate determination consists of assuming that the position of the sound source that leads to the level at the workplace is known and that there is free sound propagation from this sound source to the workplace. If 'a' is the distance sound source - workplace, a semi-spherical measurement surface with radius 'a' as well as omnidirectional emission of the sound source are assumed and the environmental influence calculated in this way.

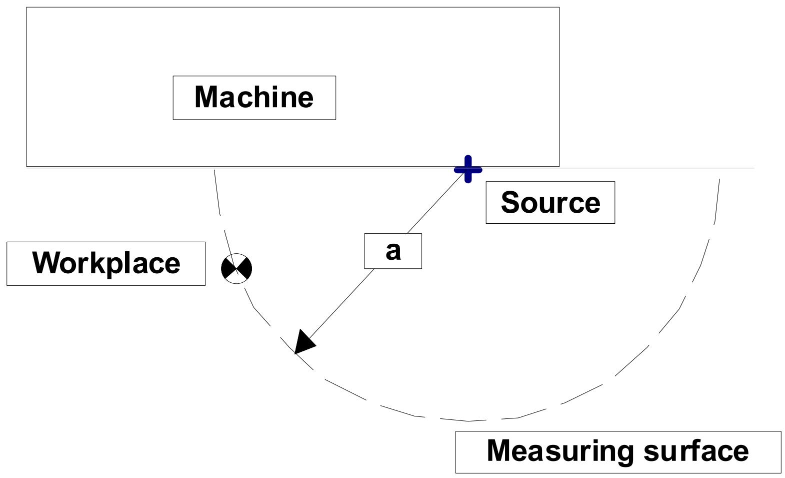

Fig. 9.1 Assumption according to ISO 11202:1996 – semi-spherical measurement surface

If the position of a determining sound source cannot be ascertained, the shortest distance of the workplace from the machine should be selected as 'a'. This then corresponds to the assumption that the entire sound power of the machine is emitted from the nearest point of the machine surface and therefore leads to the lowest possible measurement surface and lowest possible environmental influence.

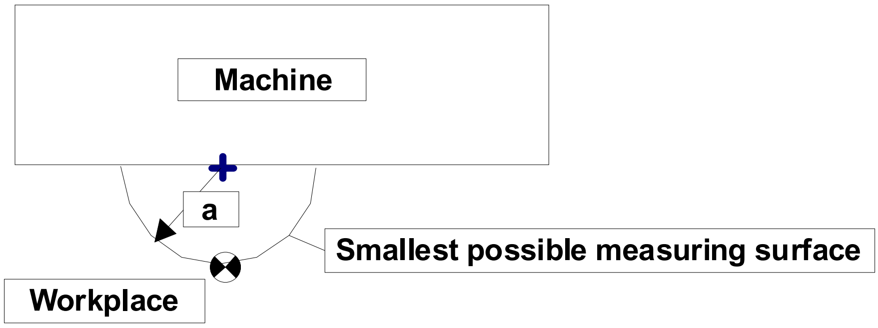

Fig. 9.2 Assumption according to ISO 11201:1996 if it is not possible to localize the source

The maximum permitted environmental correction according to this standard is 2.5 dB. This value is also used when the calculation result is a higher value. The method can be applied to rooms where the following applies

$K_{2A} \leq 7\ dB$

9.2 Deficiencies in the existing standard

As shown in /19/, the ISO 11202:1996 method leads to considerable margins of error if

- the machine is not small relative to the measuring distance and it emits on all sides
- emission takes places across large areas (expansion > distance)
- the emitting areas are screened from the workplace.

If the 'true' emission parameters L_W and L_p or their difference $L_{W\text{-}p}$ are assumed, the margin of error for determining K_3 in this way results from

$$dK_{3,202} = 10 \cdot \log\left(\frac{A + 8\pi a^2}{A + 4 \cdot 10^{0.1 \cdot L_{W-p}}}\right) dB \qquad (42)$$

As already shown, $L_{W\text{-}p}$ can be calculated for simple machine configurations using computer simulation methods. The simulated machine is assigned a certain source distribution with known total sound power level and a sound propagation calculation is used to determine the resulting sound pressure level at the workplace under free field conditions.

This simulation calculation was performed for a cubic machine with an edge length of 1 m and evenly distributed sound sources on the surface.

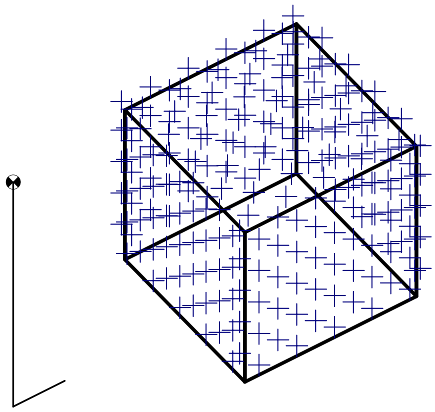

Fig. 9.3 Machine emitting from all sides – surface with 241 point sources

If the value L_{W-p} determined in this way is inserted in (42), it results in the margin of error for determining according to ISO 11202:1996 depending on the absorption area of the room according to Fig. 9.4.

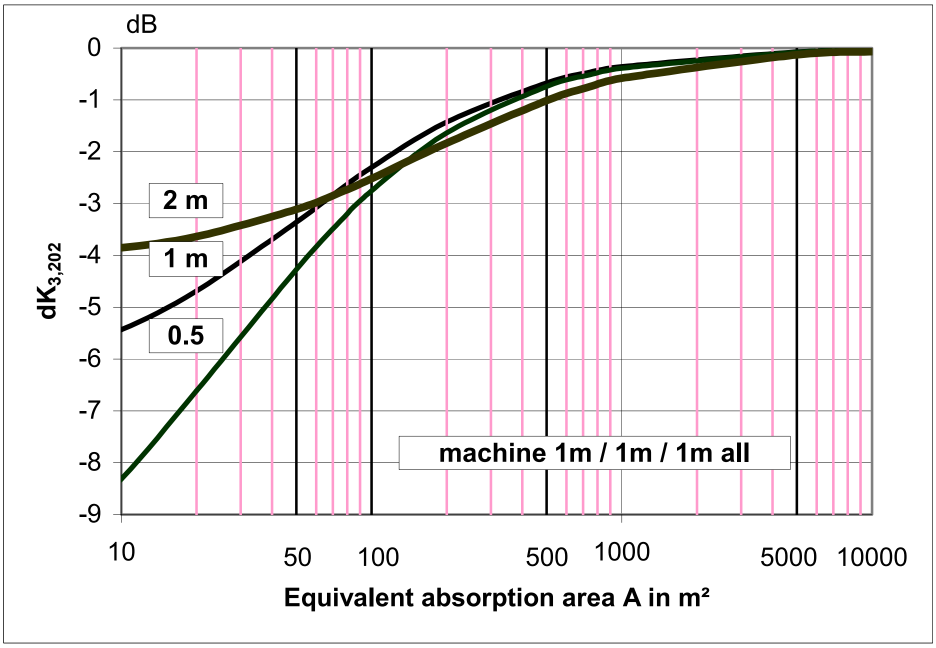

Fig. 9.4 Margin of error with application of ISO 11202:1996 for the cubic machine

The true K_3 is underestimated all the more the smaller the equivalent absorption area or the more reverberant the room is. As shown in /19/, this margin of error can certainly reach 15 to 20 dB if the source area is screened from the workplace.

An example of this is shown in Fig. 9.5. The sound emission comes from a machine table screened from the workplace by a transparent screen – as splinter and sound protection. This construction is frequently found in the bottling and packaging industry, for example.

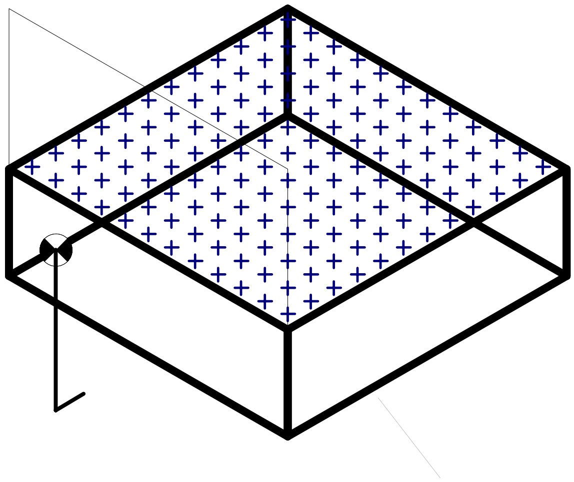

Fig. 9.5 Machine table with top-side emission and screening front screen

The described calculation of the margin of error for determining K_3 using ISO 11202 leads to the following diagram.

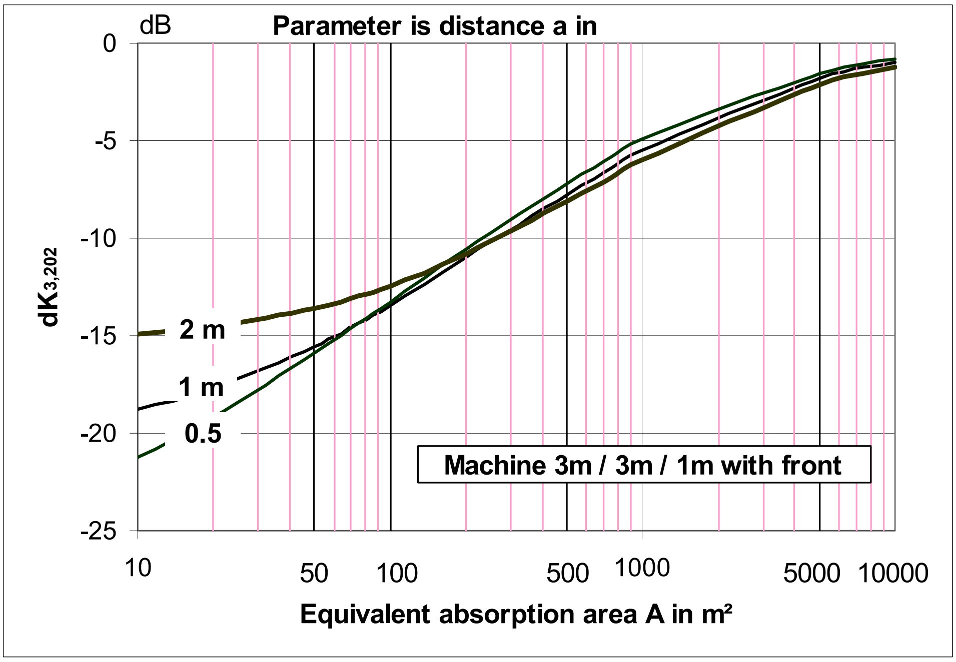

Fig. 9.6 Margin of error with application of the environmental correction according to ISO 11202 for the machine with screening front screen.

Although the screening reduces the level at the workplace in the free sound field, it does not reduce the total emitted sound power. This, however, determines the room sound pressure level, which means that a level increase corresponding to the screening measure results in the room. Fig. 9.6 shows that the margin of error in K_3 as the absorption area is reduced in size can certainly be 15 to 20 dB.

On the other hand, many investigations show that it is too restrictive to limit application of this method in general to a maximum K_3 of 2.5 dB. If the requirements for application of the method have been met – e.g. with a configuration in accordance with Fig. 8.6 at the workplace AP 1 - it is certainly the case that greater corrections can be permitted.

9.3 Proposal for a revision or new version

9.3.1 Determining the environmental correction by means of source localization

ISO 11202:200x Part 1

The machine or part of the machine emitting the major sound power is small and can be localized. This Part 1 corresponds largely to the previous standard ISO 11202:1996.

Requirement for its application:

1. The sound sources that determine the total sound emission of the machine are not screened from the workplace.

2. The machine or the part of the machine radiating the major sound power is smaller than its distance to the workplace.

3. In the case of machines that do not meet the latter condition, only a limited and localizable area of the machine surface facing the workplace determines the total emission.

Determining the emission sound pressure level:

With the distance 'a' of the source center point from the workplace and measurement surface

$$S = 2\pi a^2$$

this results in the environmental correction

$$K_3 = 10 \lg\left(1 + \frac{4S}{A}\right) \text{ dB}$$

and the emission sound pressure level

$$L_p = L_p' - K_3$$

Determining the grade:

A major uncertainty of the method is based in the definition of a characteristic distance 'a'. To determine this uncertainty, a maximum distance a_{max} of the point of the possible source area furthest away from the workplace is determined and this is used in turn to determine a maximum value of the environmental correction $K_{3,max}$. The following assignment of grade applies:

$K_{3,max} \leq 2$ dB – grade 2
2 dB < $K_{3,max} \leq 7$ dB – grade 3

9.3.2 Determining the environmental correction with approximate determination of the apparent directivity index

ISO 11202:200x Part 2

If any of the above-mentioned requirements are not met, the environmental correction is determined, taking account of an approximately ascertained apparent directivity index DI'_{approx}.

Determining the emission sound pressure level:

The sound pressure levels are measured under operating conditions that comply with the standard in front of the side centers (points P1 to P4) at distance d (d is preferably 1 m) and the energetic mean value $\overline{L}'_{approx}$ is calculated. If the design of the machine (e.g. surrounding screening with open top surface) means that it emits dominantly upwards, the top surface is to be included in determining $\overline{L}'_{approx}$.

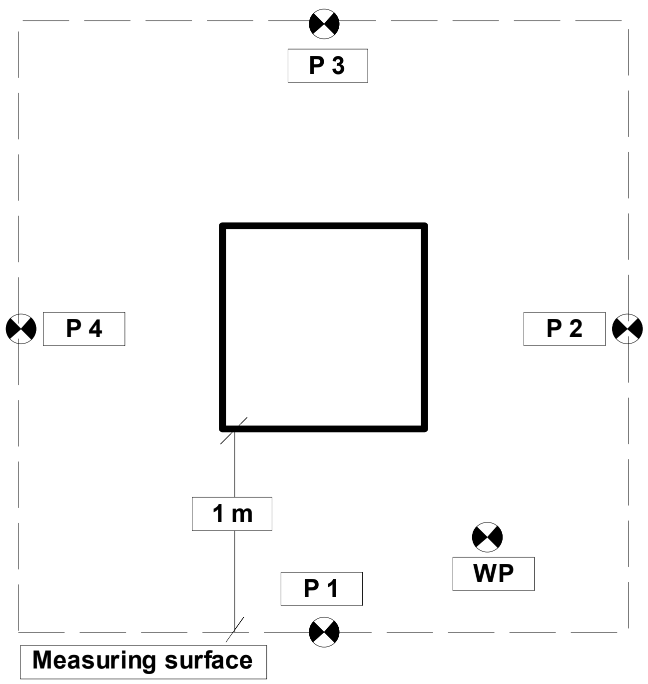

Fig. 9.7 Measuring points for determining the emission sound pressure level according to Part 3

$\overline{L}'_{approx}$ can also be determined by continuous movement of the microphone at constant speed on a path surrounding the machine at a distance of 1 m with sliding integration.

This results in the apparent and approximately determined directivity index at the workplace for

$$DI'_{approx} = L'_p - \overline{L}'_{approx} \qquad (38)$$

The environmental correction K_3 results from the assumption

$DI' = DI'_{approx}$

with

$$K_3 = -10 \cdot \log\left[1 - \left(1 - 10^{-0.1 \cdot K_2}\right) \cdot 10^{-0.1 \cdot DI'}\right] dB \qquad (25)$$

It can be ascertained in line with Fig. 9.8.

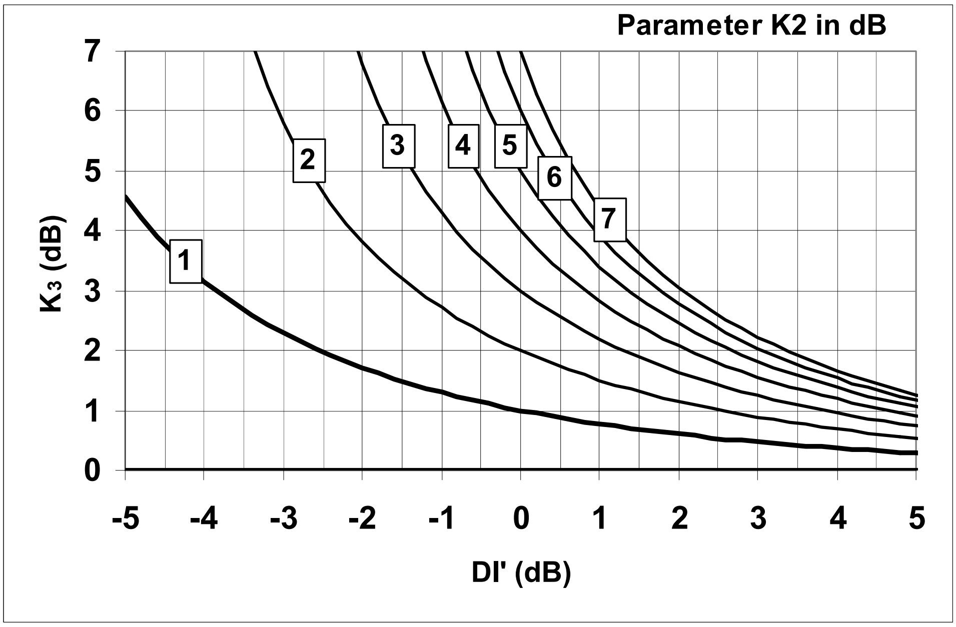

Fig. 9.8 Determining K_3 with K_2 and DI’

Determining the grade:
With DI'$_{approx}$ according to (38) and K_2 according to (6), the grade results from Fig. 9.9.

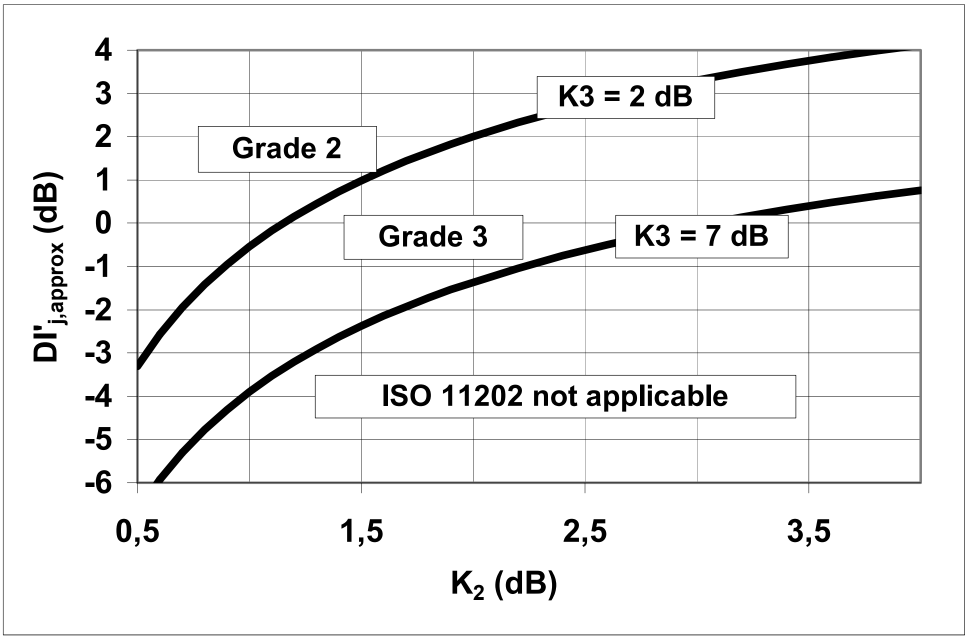

Fig. 9.9 Determining the grade from K_2 and DI'$_{approx}$

9.4 Application example

The method described in 9.3.2 greatly extends the range of application of ISO 11202. Part 1, with which the source area is assumed to be small and the sound propagation to be semi-spherical for any size of machine. Now it also includes the frequent case of a machine with dimensions small relative to the measuring distance. This also applies to larger acoustically transparent machine frames with a small spatial subarea that radiates the sound energy.

However, this also applies to an encapsulated machine with a supply and discharge opening through which the major proportion of noise is emitted. The level at the workplace is measured, its distance 'a' from this opening is determined, and the correction is performed.

Part 2 creates a possibility to include any type of machines. In contrast to ISO 11204 it is sufficient to determine the directivity index at the specified position approximately. This is then taken into account in specifying the grade of uncertainty, allowing for a margin of error of 2 dB for the directivity index.

As an example, the already familiar machine with one-sided point source from Fig. 9.10 will be examined.

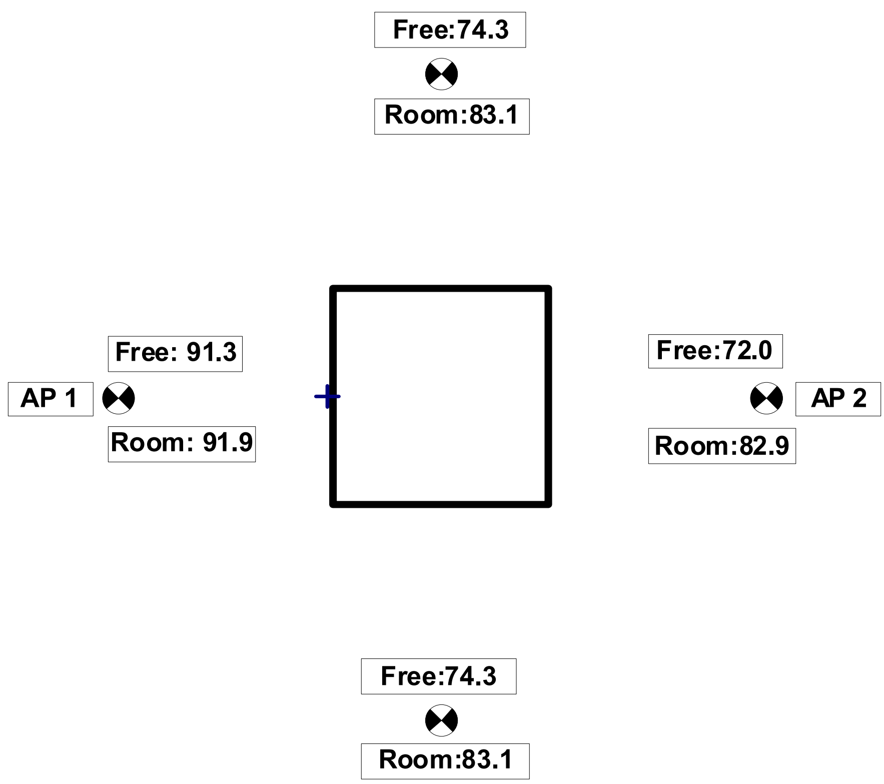

Fig. 9.10 Levels at four sides with measurement in the free sound field and in the room with 225 m² absorption area

Measurement in the room provides an energetic mean value of the 4 level in front of the side centers of 87.3 dB and – as already discussed at 11.4 - a directivity index DI'_{approx} of

4.6 dB at AP 1
-4.4 dB at AP 2

According to this proposal ISO 11201:200x, the grade results from Fig. 9.9 and the environmental correction K_3 from (23) or Fig. 9.8. This results for

AP 1 – grade 2 – L_p = 91.4 dB
AP 2 – determination according to this standard is not possible

The result at AP 1 is therefore more exact because of application of the correction - in contrast to ISO 11201. In the screened area AP 2, ISO 11202 cannot be applied in this room either.

10 ISO 11204 – existing deficiencies and proposal for improvement

10.1 Essential content of the existing standard

The result determined using this method is allocated to grade 2 or 3 – depending on the size of the environmental correction K_3 applied.

The environmental correction K_3 is determined taking account of the room properties – expressed as equivalent absorption area A or as environmental correction K_2 referring to a measurement surface S – as well as the apparent directivity index DI' of the specified workplace measurement point using the following relationships.

$$K_3 = -10 \cdot \log\left(1 - \frac{1}{1 + \frac{A}{4 \cdot S}} \cdot 10^{-0.1 \cdot DI'}\right) dB \qquad (23)$$

and

$$K_3 = -10 \cdot \log\left[1 - \left(1 - 10^{-0.1 \cdot K_2}\right) \cdot 10^{-0.1 \cdot DI'}\right] dB \qquad (25)$$

The method is restricted to rooms with a K_2 referring to the machine lesser than or equal to 7 dB.

With the 'Technical Corrigendum 1' of 1997, the range of application was limited even more. This means the application for a negative directivity index

DI' $\leq$ -3 dB

is only permitted if the K_3 resulting from (23) or (25) is a maximum of 2 dB.

10.2 Deficiencies in the existing standard

The deficiency in the standard is the fact that with negative directivity indices – i.e. level minimum at the workplace point – the argument of the logarithm function in (23) or (25) can become slightly negative, which means that no solution can be achieved with calculation.

It is simply a fact that the method becomes less precise the larger the correction is. The curves in Fig. 9.8 become increasingly steep as the directivity index DI' gets smaller, which means than even small measurement errors for DI' (or for L'_p or $\overline{L'}_p$) can lead to considerable deviations in the determined K_3.

With research report Fb 968 /10/ it was shown that an error in K_3 resulting from an error of 1 dB in the used DI' value depends strongly on the absolute height of the determined K_3-value (Figure 10.1). showed that the margin of error in K_3 for the error assessment of DI' depends on the value of K_3 itself by one dB above the function shown in Fig. 10.1 (in the diagram, L_W is chosen as reference – it can be replaced directly by L'_p or $\overline{L}'_p$).

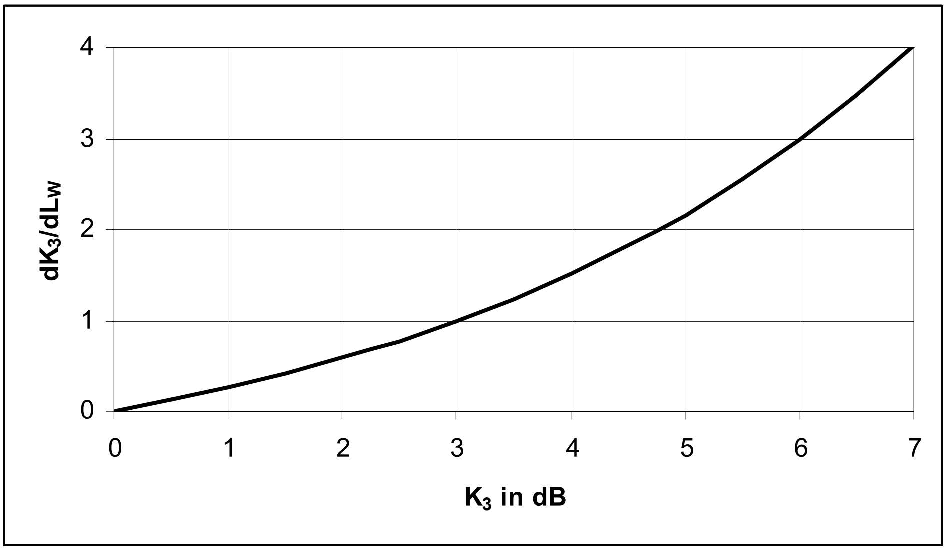

Fig. 10.1 Error in K_3 resulting from an error of 1 dB in the assumed L_W value in dependence of the 'true' value of K_3

The diagram shows that a 'true' influence of the room according to a K_3 of 3 dB leads to an error of the determined K_3 that is identical to the error of the determined L_W, L'_p or $\overline{L}'_p$.

However, it also shows that this error in K_3 is 3 times the error in L_W, L'_p or $\overline{L}'_p$ if K_3 equals 6 dB.

This makes it obvious that with high K_3 values considerable deviations can occur - even due to the uncertainties inherent in the method - and that this can even result in the equations becoming unsolvable.

10.3 Proposal for a revision or new version

The problems mentioned can be remedied by introducing a two-stage method in the calculation of the environmental correction.

In the first step, the argument 'z' of the logarithm function in (23) or (25) is calculated. If this argument is less than the value z_{limit}, for which K_3 assumes the value of 7 dB, this minimum value z_{limit} is used in the second step to calculate K_3.

This method also means that ISO 11204 can be applied in all cases. However, the emission sound pressure level determined in this way becomes more imprecise the more the 'true' room influence exceeds the value of 7 dB. If using this 'estimate' specified in a standard manner results in an environmental correction of 7 dB, and in the end an emission sound pressure level of X dB, the following should always be specified:

Emission sound pressure level $L_p \leq$ X dB(A), grade 3

Equation (A.2) of ISO 11204 is modified in the following manner:

$$z = 1 - \left(1 - 10^{-0{,}1 \cdot K}\right) \cdot 10^{-0{,}1 \cdot DI'} \qquad (43)$$

and

$$K_{3,j} = \begin{cases} 7 & \text{for } z \leq 0.2 \\ -10 \cdot \lg(z) & \text{for } 0.2 < z \leq 1 \\ 0 & \text{for } z > 1 \end{cases} \qquad (44)$$

In a similar manner, equation (A.4) is modified:

$$z = 1 - \frac{1}{1 + \frac{A}{4S}} \cdot 10^{-0.1 \cdot DI'} \qquad (45)$$

and

$$K_{3,j} = \begin{cases} 7 & \text{for } z \leq 0.2 \\ -10 \cdot \lg(z) & \text{for } 0.2 < z \leq 1 \\ 0 & \text{for } z > 1 \end{cases} \qquad (46)$$

An extension of the application possibilities for ISO 11204 results from the calculation of K_3 from the sound power level L_W and the uncorrected sound pressure level at the workplace L'_p in accordance with

$$\underline{K_3 = -10 \cdot \lg\left(1 - \frac{4 \cdot A_0}{A} \cdot 10^{0{,}1\left(L_W - L'_p\right)}\right) dB} \qquad (26)$$

or after replacement of A by K_2 in

$$\underline{K_3 = 10 \cdot \lg\left(1 - \frac{S_0}{S}\left(10^{0{,}1K_2} - 1\right) \cdot 10^{0{,}1\left(L_W - L'_p\right)}\right) dB} \qquad (27)$$

This can be an advantage if machines with complicated shapes and installations make the measurement on an enveloping surface area too complex/expensive and the sound power level can be gained from a measurement according to ISO 3747 or with intensity measurement according to ISO 9614. As no measurement takes place on an enveloping surface area surrounding the source in this case, K_2 is determined using the comparative sound source on a semi-spherical surface area S in accordance with ISO 6926, section 7.3.3 /11/ (see also chapter 2.3).

In this case a notation in accordance with (44) should be used, whereby

$$z = 1 - \frac{4 \cdot A_0}{A} \cdot 10^{0{,}1\left(L_W - L_p'\right)} \qquad (48)$$

is first calculated and the in a second step the environmental correction is determined using (44).

10.4 Application example

As an example, the already familiar machine with one-sided point source from Fig. 10.2 will be examined in this case, too.

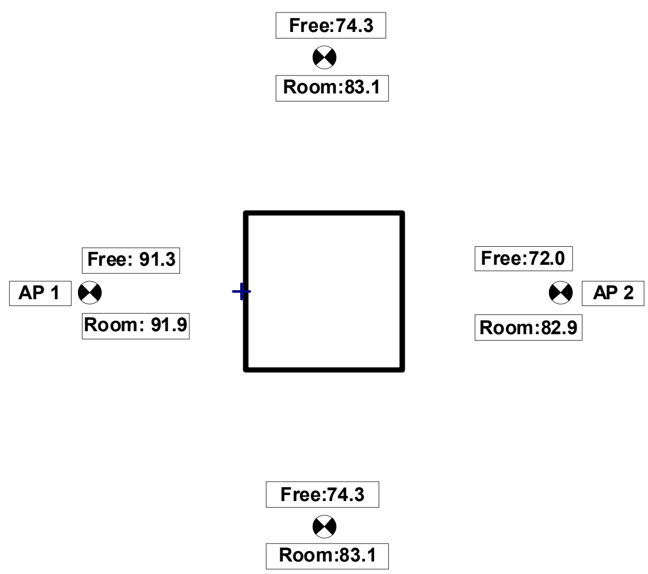

Fig. 10.2 Levels at four sides with measurement in the free sound field and in the room with 225 m² absorption area

However, ISO 11204 demands a measurement of the mean sound pressure level on the entire measurement surface that complies with the standard, which means that in this case other measuring points – e.g. above the machine – would certainly be required. To explain the principle, however, the same 4 points as in the previous application examples are assumed.

This means the energetic mean value of the 4 levels in front of the side centers is 87.3 dB and the evaluation of (45) and (46) results in the following:

Workplace	**DI' in dB**	**z**	**K_3 in dB**	**L_p in dB**	**Deviation dB**	**Grade**
AP 1	4.6	0.872	0.6	91.3	0	2
AP 2	- 4.4	0.016	7	≤ 76.0	4	3

This means both results and/or the deviations to the forecast grade are compatible – as regards the value for Workplace 2, the user of the emission sound pressure level is informed that this is an upper limit for L_p.

11 The logic of the series of standards 11200:new according to the submitted proposals – a summary

The two emission parameters sound power level and emission sound pressure level describe the sound emission of a machine – they can be determined using measuring techniques e.g. in the free sound field, i.e. operation of the machine outdoors or in a room equipped for high absorption.

However, it must also be possible for the operator of a machine that cannot be moved after its installation and commissioning to verify a noise emission value specified by the manufacturer. This measurement *in situ* is the decisive problem for standardization of noise measurement methods.

Although determining the sound power level under free field conditions involves significantly more time effort than for the emission sound pressure level – which only requires a single simple sound pressure level measurement with a standard sound level meter – the conditions in a room are turned around due to the environmental influence.

In measuring the sound power level, there is – at least for experts that have the required measuring technology and can also use it – the possibility to measure the sound intensity directly and therefore to eliminate the influence of the room.

This is only possible to a limited degree on determining the emission sound pressure level using measuring techniques. Although the standard ISO 11205 also provides a possibility to use a 3-axis intensity measurement to determine the approximate emission sound pressure level without the need for an environmental correction, this is just what purports to be - a method of approximation - which certainly has the application limits and uncertainties comparable to those in the sound pressure method. In contrast to determining the sound power level, the sound intensity is not a variable from which the target parameter can be derived theoretically – it is only under certain ideal conditions with an ideal and completely diffuse sound field at the specified position, that the room sound field would not influence the result of the measurement obtained with an intensity probe.

Although the emission sound pressure level only requires the simple sound pressure level measurement at one point, the ISO 11200 series presents a whole range of measurement regulations that differ through nothing but precisely the elimination of the environmental influence from the measurement result.

The contribution of the room sound field to the sound pressure level at the workplace created due to the noise emission of the machine can de derived using the statistical sound field theory from the recordable technical parameters. We have developed this method and with ISO 11204 introduced into the international standardization as a proposal for environmental correction.

With ISO 11201 and ISO 11202, more methods that only differ with regard to treatment of the environmental influence have been standardized. None of these methods uses anything other than the assumptions based on the statistical sound field theory.

Although this requirement of statistical theory is often criticized as imprecise and inapplicable, it is to date the only method of description that can be handled quantitatively and that can also be implemented in unambiguous instructions. All other calculation methods of the secondary sound field created in the room such as the mirror source method, sound particle model or others are only sound field simulations that can be run on computing programs that are still a long way from being able to provide the measuring technician on site with an aid to decision-making in determining emission parameters.

The proposals presented here accept the consequences from investigations into and experience with application of these standards to date.

In ISO 11201, Part 1 integrates a reference method of grade 1. Here, the sound pressure level measurement at the workplace is carried out in an environment in which no influence of the room or only a negligibly small influence of the room is expected.
ISO 11201, Part 2 describes the same grade 1 measurement with negligible environmental influence outside. This corresponds to a practice already used by many machine manufacturers – they measure their products on a random sample basis on larger outdoor areas of the company premises.
ISO 11201, Part 3 allows to define the grade of accuracy of the emission sound pressure level, that has directly been measured at the workplace in situ without any correction for environmental influence on the basis of the acoustic properties of the room. It shall be mentioned, that this part 3 method is not recommended for the short term revision of ISO 11201.

A major feature of all methods according to ISO 11201 is that no environmental correction is applied.

For ISO 11202, simplified determination of the environmental correction is enabled in two ways.

The first method can be applied if a spatially limited source area that is small in relation to the measuring distance causes the major sound emission. According to our proposal, this method can also be applied if the entire machine is small relative to the measuring distance.

A second method permits approximate inclusion of the total emission or directivity of this emission and therefore application of the standard also in cases in which it could not be applied previously or would have led to considerable margins of error.

In both cases, procedures are offered that enable assignment of the result to grade 2 or 3.

An essential feature of all methods according to ISO 11202 is therefore that an environmental correction is determined using simplified methods and also applied.

ISO 11204 is relieved of one formal deficiency that prevented its application in many cases. This concerns the specification of a maximum environmental correction of 7 dB also in cases in which the calculation would result in a greater correction or in which the calculation formula no longer delivers a solution. Physically, this means that the level proportion of the room sound field to be eliminated lies so far above the level of the direct sound field of the machine or the 'wanted signal' that it can no longer be calculated using level differences (nothing else is the application of correction methods).

Procedures for assignment of an uncertainty or a grade are also specified for determination according to ISO 11204.

An essential feature of the method according to ISO 11204 is that the total emission for determining the directivity index at the workplace is determined without approximation and that the environmental correction ascertained in this way is applied.

In all three cases ISO 11201, ISO 11202 and ISO 11204 the uncertainty when measuring impulsive noise can be taken into account using the method described in /23/ and /24/.

This means that there is a conclusive and consistent concept for determining the emission sound pressure level. If a measurement is to be carried out or the method is to be specified for a certain machine type on a machine-specific basis, a check is run in the order

ISO 11201 -> ISO 11202 -> ISO 11204 (-> ISO 11205)

as to whether a measurement is possible with the current – or typically prevailing – conditions and whether the accuracy that can be achieved with it is acceptable. If any of these questions is answered in the negative, the check is run using the next standard in this series. The required time effort rises accordingly. As the first 3 standards are exclusively various approximations for handling the environmental influence on the basis of sound pressure level measurements, whereby the same theoretical assumptions about the description of the acoustic room influence are used as basis, these can be integrated in a single standard on long term.

This would have the advantage that the individual methods would be regarded as modules which could be combined as desired depending on the defined task. For examples, see Appendix 5.

Whether the concepts presented here are to be implemented in a short-term or long-term revision of the ISO 11200 series of standards (and if so, which of the concepts) will have to be decided by the working group. This report is intended to create a basis.

12 Bibliography

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/3/	9. GSGV	9. Ordinance for Device Safety Act (9th GSGV) and for changes of Ordinance for Device Safety Act of May 12, 1993. GB Bl I (1993) page 704
/4/	ISO 11201	Acoustics - Noise emission of machines and devices - Measurement of emission sound pressure levels at the workplace and other specified locations; Method of grade 2 for an essentially free sound field above a reflecting level surface, Beuth Verlag GmbH, Berlin 1996
/5/	ISO 11202	Acoustics - Noise emission of machines and devices - Measurement of emission sound pressure levels at the workplace and other specified locations; Method of grade 3 for measurements under deployment conditions, Beuth Verlag GmbH, Berlin 1996
/6/	ISO 11203	Acoustics - Noise emission of machines and devices - Determining emission sound pressure levels at the workplace and at other specified locations from the sound pressure level, Beuth Verlag GmbH, Berlin 1996
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Appendix 1 Investigation to determine the equivalent absorption area using the comparative sound source

Investigation based on measurements

In section 2.3 a method was proposed that can be used to determine the equivalent absorption area A of a room from the measurement of the sound pressure level on a semi-spherical enveloping surface area around a reference sound source (RSS). The starting point is the relationship that describes the level addition caused by the room:

$$K_2 = 10\lg\left(1 + \frac{4 \cdot S}{A}\right) dB \qquad (1)$$

This results in the equivalent absorption area as a function of this level increase

$$A = \frac{4 \cdot S}{10^{0,1 \cdot K_2} - 1} \qquad (2)$$

With reference to the sound power level L_W of the RSS and of the mean sound pressure level on the enveloping surface area $\overline{L}'$, this can also be written as

$$A = \frac{4 \cdot S}{\frac{S}{S_0} \cdot 10^{0,1 \cdot (\overline{L}' - L_W)} - 1} \qquad (3)$$

This method would be of great interest in particular if it could also be applied in rooms of any shape and equipped in any way. In a manner of speaking, the RSS determines the local level increase and thus also a 'locally effective' equivalent absorption area A. The transformation (2) or (3) is also possible if the sound field is not diffuse or if it does not correspond to the laws of statistical theory. If this A is used to calculate the level increase at a machine, only the 'local' room feedback is included in effect. The remaining margin of error results from the difference between the level on the RSS measurement surface and the machine measurement surface if the propagation deviates from that which would be expected according to statistical theory. If the measurement surfaces are the same size, only the different source emission with respect to directivity remains as an error source.

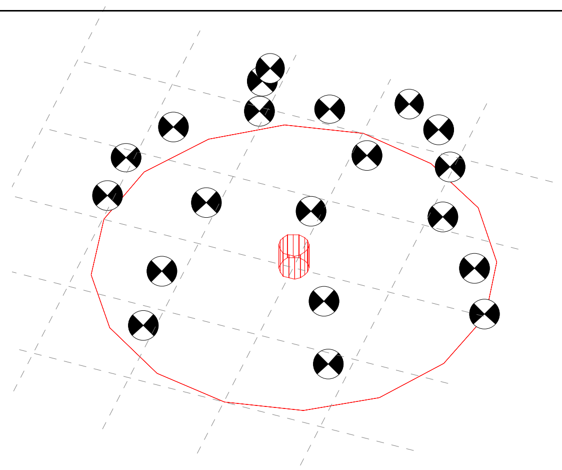
Experience shows that different methods for determining a parameter in acoustics often lead to different results or that – in other words – the accuracy is often low even if a method is more precise. This is taken into account in the recommendation that only one defined method should be used for a given machine family, even if more possible alternatives exist. If, as in the present case, different methods are to be permitted in order to be able to determine a certain parameter in as many scenarios as possible, it should be taken into account which random and systematic deviations are to be expected.

However, this cannot be examined within the framework of this investigation with the required depth.

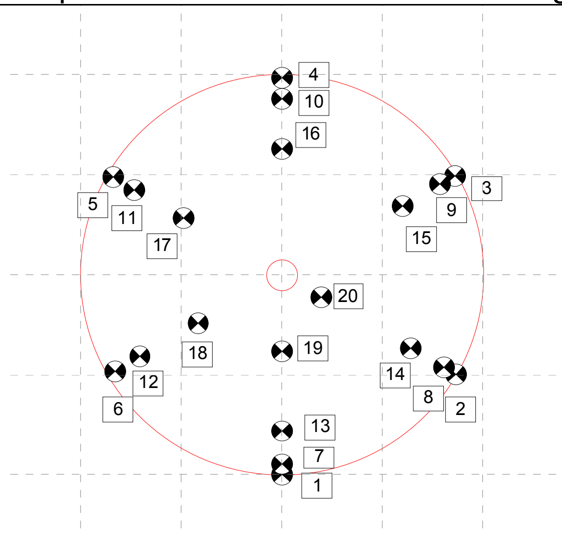
In order to obtain a first impression of the practicability of the method, both methods – measurement of the reverberation period and measurement of the sound pressure level on the semi-spherical measurement surface area of the RSS – were used to determine A in 3 different rooms of an office building under construction.

One of these rooms is a reverberant room corresponding to ISO 3741 in which no diffusors have yet been placed.

The measuring points were arranged according to table 2.1 as a spiral path. Appendix 1, Fig. 1 and Fig. 2 show this arrangement:



Appendix 1, Fig. 1 Oblique view of the measurement arrangement



Appendix 1, Fig. 2 Ground plan of the measurement arrangement

The following tables show the results separately for one-third octave and octave bands. The individual column headers mean

Leq	Mean sound pressure level measured in the room on the measurement surface
L_W	Sound power level as specified by the manufacturer (not corrected)
A(7b)	Equivalent absorption area according to equation (3)
T	Reverberation time

A(T) Equivalent absorption area calculated from the measured reverberation time

dA/A Relative error for determining A according to (3)

10lg(dA/A) Error in dB for assessment of the room sound pressure level resulting from this error of A

Appendix 1, Table 1 Room 1 (reverberant room unfinished construction, S = 25 m², V = 237 m³)

Frequency	Leq Measurement	Lw Specifi-cation	A (7b)	T	A (T)	dA /A relative	Deviation
Hz	dB	dB	m^2	s	m^2	difference	dB
100	72.8	75.8	**8.7**	10.90	**3.5**	**1.5**	**3.9**
125	73.6	76.4	**8.3**	11.83	**3.3**	**1.5**	**4.1**
160	74.3	77.3	**8.6**	10.11	**3.8**	**1.2**	**3.5**
200	75.4	77.4	**6.7**	9.51	**4.1**	**0.7**	**2.2**
250	74.9	76.6	**6.2**	9.22	**4.2**	**0.5**	**1.7**
315	74.5	76.6	**6.9**	9.24	**4.2**	**0.6**	**2.2**
400	75.1	76.7	**6.1**	9.52	**4.1**	**0.5**	**1.8**
500	74.8	76.9	**6.9**	8.96	**4.3**	**0.6**	**2.1**
630	75.9	77.2	**5.7**	8.66	**4.5**	**0.3**	**1.1**
800	77.2	79.0	**6.5**	7.85	**4.9**	**0.3**	**1.2**
1000	77.9	80.4	**7.6**	6.89	**5.6**	**0.4**	**1.3**
1250	79.3	82.2	**8.4**	6.46	**6.0**	**0.4**	**1.5**
1600	79.3	82.3	**8.7**	5.73	**6.7**	**0.3**	**1.1**
2000	78.1	81.6	**9.9**	4.90	**7.9**	**0.3**	**1.0**
2500	75.7	79.7	**11.3**	4.26	**9.1**	**0.2**	**0.9**
3150	74.3	79.5	**15.1**	3.71	**10.4**	**0.5**	**1.6**
4000	72.9	79.0	**19.3**	3.02	**12.8**	**0.5**	**1.8**
5000	70.5	78.2	**30.7**	2.51	**15.4**	**1.0**	**3.0**
6300	68.0	77.2	**49.2**	1.94	**19.9**	**1.5**	**3.9**
8000	64.7	75.5	**93.6**	1.55	**25.0**	**2.7**	**5.7**
10000	60.8	73.2	**232.0**	1.11	**34.9**	**5.7**	**8.2**

Frequency	Leq Measurement	Lw Specifi-cation	A (7b)	T	A (T)	dA /A relative	Deviation
Hz	dB	dB	m^2	s	m^2	difference	dB
125	78.4	81.3	**8.5**	10.96	**3.5**	**1.4**	**3.8**
250	79.8	81.7	**6.7**	9.32	**4.1**	**0.6**	**2.1**
500	80.1	81.7	**6.2**	9.05	**4.3**	**0.5**	**1.6**
1000	83.0	85.5	**7.6**	7.07	**5.5**	**0.4**	**1.4**
2000	82.7	86.1	**9.6**	4.96	**7.8**	**0.2**	**0.9**
4000	77.6	83.7	**19.3**	3.08	**12.6**	**0.5**	**1.9**
8000	70.2	80.4	**71.7**	1.53	**25.2**	**1.8**	**4.5**

Appendix 1, Table 2 Room 2 (flat room in unfinished office construction, S = 25 m², V = 691 m³)

Frequency	Leq Measurement	Lw Specifi-cation	A (7b)	T	A (T)	dA /A relative	Deviation
Hz	dB	dB	m²	s	m²	difference	dB
100	66.4	75.8	**52.9**	4.56	**24.7**	**1.1**	**3.3**
125	67.0	76.4	**53.8**	3.82	**29.5**	**0.8**	**2.6**
160	67.1	77.3	**71.6**	3.39	**33.2**	**1.2**	**3.3**
200	66.7	77.4	**89.4**	3.48	**32.4**	**1.8**	**4.4**
250	66.8	76.6	**61.8**	3.35	**33.6**	**0.8**	**2.7**
315	67.2	76.6	**52.7**	3.24	**34.8**	**0.5**	**1.8**
400	67.7	76.7	**47.2**	3.15	**35.8**	**0.3**	**1.2**
500	68.3	76.9	**40.2**	3.71	**30.4**	**0.3**	**1.2**
630	70.0	77.2	**26.4**	4.02	**28.0**	**-0.1**	**-0.3**
800	71.8	79.0	**26.7**	4.00	**28.1**	**-0.1**	**-0.2**
1000	72.4	80.4	**33.5**	3.79	**29.7**	**0.1**	**0.5**
1250	74.0	82.2	**35.4**	3.80	**29.7**	**0.2**	**0.8**
1600	74.1	82.3	**35.7**	3.64	**31.0**	**0.2**	**0.6**
2000	73.1	81.6	**39.6**	3.34	**33.7**	**0.2**	**0.7**
2500	70.9	79.7	**43.8**	3.15	**35.7**	**0.2**	**0.9**
3150	69.8	79.5	**58.3**	2.71	**41.5**	**0.4**	**1.5**
4000	68.8	79.0	**72.9**	2.17	**51.8**	**0.4**	**1.5**
5000	66.8	78.2	**125.1**	1.82	**61.7**	**1.0**	**3.1**
6300	65.0	77.2	**199.0**	1.36	**82.9**	**1.4**	**3.8**
8000	62.3	75.5	**481.5**	1.13	**99.4**	**3.8**	**6.9**
10000	59.1	73.2		0.79			

Frequency	Leq Measurement	Lw Specifi-cation	A (7b)	T	A (T)	dA /A relative	Deviation
Hz	dB	dB	m²	s	m²	difference	dB
125	71.6	81.3	**59.0**	3.81	**29.5**	**1.0**	**3.0**
250	71.7	81.7	**67.1**	3.39	**33.2**	**1.0**	**3.1**
500	73.6	81.7	**35.2**	3.66	**30.8**	**0.1**	**0.6**
1000	77.6	85.5	**32.4**	3.86	**29.2**	**0.1**	**0.5**
2000	77.7	86.1	**38.6**	3.32	**33.9**	**0.1**	**0.6**
4000	73.4	83.7	**74.5**	2.24	**50.3**	**0.5**	**1.7**
8000	67.5	80.4	**335.9**	1.09	**103.1**	**2.3**	**5.1**

Appendix 1, Table 3 Room 3 (flat room in unfinished office construction, S = 25 m², V = 770 m³)

Frequency	Leq Measurement	Lw Specification	A (7b)	T	A (T)	dA /A relative	Deviation
Hz	dB	dB	m²	s	m²	difference	dB
100	67.3	75.8	**39.1**	4.48	**28.0**	**0.4**	**1.4**
125	67.6	76.4	**43.5**	4.08	**30.8**	**0.4**	**1.5**
160	67.9	77.3	**54.1**	3.77	**33.3**	**0.6**	**2.1**
200	68.4	77.4	**45.9**	3.33	**37.7**	**0.2**	**0.9**
250	68.4	76.6	**36.2**	3.28	**38.3**	**-0.1**	**-0.2**
315	68.6	76.6	**33.5**	3.37	**37.3**	**-0.1**	**-0.5**
400	68.4	76.7	**36.8**	3.33	**37.7**	**0.0**	**-0.1**
500	69.1	76.9	**32.0**	3.61	**34.8**	**-0.1**	**-0.4**
630	70.6	77.2	**22.6**	4.01	**31.3**	**-0.3**	**-1.4**
800	72.5	79.0	**21.7**	4.14	**30.3**	**-0.3**	**-1.4**
1000	73.2	80.4	**26.9**	4.08	**30.7**	**-0.1**	**-0.6**
1250	74.6	82.2	**29.7**	3.83	**32.8**	**-0.1**	**-0.4**
1600	74.7	82.3	**30.3**	3.71	**33.9**	**-0.1**	**-0.5**
2000	73.7	81.6	**32.9**	3.30	**38.1**	**-0.1**	**-0.6**
2500	71.5	79.7	**35.9**	3.03	**41.4**	**-0.1**	**-0.6**
3150	70.5	79.5	**46.5**	2.75	**45.7**	**0.0**	**0.1**
4000	69.3	79.0	**60.0**	2.32	**54.0**	**0.1**	**0.5**
5000	67.0	78.2	**109.0**	1.90	**66.0**	**0.7**	**2.2**
6300	65.1	77.2	**188.0**	1.51	**83.0**	**1.3**	**3.6**
8000	62.2	75.5	**581.0**	1.19	**105.0**	**4.5**	**7.4**
10000	58.8	73.2		1.15	**109.0**		

Frequency	Leq Measurement	Lw Specification	A (7b)	T	A (T)	dA /A relative	Deviation
Hz	dB	dB	m²	s	m²	difference	dB
125	72.4	81.3	**45.4**	4.11	**30.5**	**0.5**	**1.7**
250	73.2	81.7	**38.8**	3.32	**37.8**	**0.0**	**0.1**
500	74.2	81.7	**28.9**	3.70	**34.0**	**-0.1**	**-0.7**
1000	78.3	85.5	**26.6**	4.08	**30.7**	**-0.1**	**-0.6**
2000	78.2	86.1	**32.3**	3.30	**38.0**	**-0.1**	**-0.7**
4000	73.9	83.7	**60.9**	2.32	**54.0**	**0.1**	**0.5**
8000	67.5	80.4	**349.0**	1.32	**95.3**	**2.7**	**5.6**

The results show that the deviations in the middle frequency range related to level sizes are relatively low. How the greater deviations in the boundary frequency ranges affect the total margin of error depends on the spectrum of the machine.

The results shown lead to the assumption that determining a locally effective equivalent absorption area A and applying these values of A to determine the environmental correction K_2 for a machine achieves sufficient accuracy if the A-weighted sound power level of the machine is the target variable. As the investigation shows, the results in the frequency bands are uncertain in low and high frequencies.

Accuracy in determining the sound power level

The question now arises about the influence of the deviations shown above for the individual frequency bands on the accuracy of the recently ascertained A-weighted sound power level.

The following error propagation is to be taken into account if the errors related to frequency bands when determining the equivalent absorption area A are known:

1. the band-related error dA_j result in band-related errors $dK_{2,j}$
2. the band-related errors $dK_{2,j}$ result in band-related error $dL_{W,j}$
3. the band-related errors $dL_{W,j}$ result in an error dL_W of the determined sound power level

Here, $dL_{W,j}$ and dL_W can be replaced by the corresponding variables dL_j and dL related to the sound pressure level on the measurement surface, because the latter is only distinguished from the sound power level variables by the measurement surface S that is not regarded here as uncertain.

Step 1:

$$K_2 = 10\lg\left(1 + \frac{4S}{A}\right) dB = f(A) \quad (4)$$

$$dK_2 = \frac{\partial K_2}{\partial A} \cdot dA \quad (5)$$

With (Axx.4)

$$\frac{\partial K_2}{\partial A} = -\frac{10\lg(e)}{A \cdot \left(1 + A/4S\right)} \quad (6)$$

The following therefore applies

$$dK_2 = \frac{\partial K_2}{\partial A} \cdot dA = -\frac{10\lg(e)}{\left(1 + A/4S\right)} \cdot \frac{dA}{A} \quad (7)$$

Step 2:

With the measured levels L'_j (A-weighted) and the environmental correction $K_{2,j}$ in the frequency band j, the A-weighted, corrected level on the measurement surface results from

$$L = 10\lg\left(\sum 10^{0,1\left(L'_j - K_{2,j}\right)}\right) dB \quad (8)$$

If the band-related $K_{2,j}$ are uncertain with $dK_{2,j}$, the error in L is

$$dL = \frac{\partial L}{\partial K_{2,1}} \cdot dK_{2,1} + \frac{\partial L}{\partial K_{2,2}} \cdot dK_{2,2} + ... = \sum_j \frac{\partial L}{\partial K_{2,j}} \cdot dK_{2,j} \quad (9)$$

The partial derivation related to the band n is

$$\frac{\partial L}{\partial K_{2,j=n}} = -\frac{10^{0,1\left(L'_n - K_{2,n}\right)}}{\sum_j 10^{0,1\cdot\left(L'_j - K_{2,j}\right)}} \qquad (10)$$

Step 3:

With (9) and (10), the resulting margin of error in the A-weighted total level is

$$dL = -\sum_n \frac{10^{0,1\left(L'_n - K_{2,n}\right)}}{\sum_j 10^{0,1\left(L'_j - K_{2,j}\right)}} \cdot dK_n \qquad (11)$$

or

$$dL = -\frac{\sum_n dK_n \cdot 10^{0,1\left(L'_n - K_{2,n}\right)}}{\sum_j 10^{0,1\left(L'_j - K_{2,j}\right)}} \qquad (12)$$

(Axx.3) leads to

$$dK_n = -\frac{10\lg(e)}{\left(1 + A/4S\right)} \cdot \frac{dA_n}{A_n} \qquad (13)$$

and the following therefore applies

$$dL = \frac{10\lg(e)}{\sum_j 10^{0,1\left(L'_j - K_{2,j}\right)}} \cdot \sum_n \left(\frac{10^{0,1\left(L'_n - K_{2,n}\right)}}{1 + A_n/4S} \cdot \frac{dA_n}{A_n} \right) \qquad (14)$$

By eliminating the K_2 with (Axx.10), the total margin of error in the A-weighted level results from

$$dL = \frac{10\lg(e)}{\sum_j \frac{10^{0,1\cdot L'_j}}{\left(1 + 4S/A_j\right)}} \cdot \sum_n \left(\frac{A_n}{4S} \cdot \frac{10^{0,1\cdot L'_n}}{\left(1 + \frac{A_n}{4S}\right)^2} \cdot \frac{dA_n}{A_n} \right) \qquad (15)$$

The two totals are kept separate. (Axx.15) can be used to estimate the total error from the band-related values of the equivalent absorption area A determined using RSS and the equally band-related uncorrected level on the measurement surface L' using the relative error dA_n/A_n taken from the tables Appendix 1, Table 1 to Table 3.

Appendix 2 Translation to standard conditions (based on Wittstock)

For sound power *P*, (*r* – air density, *c* – speed of sound in air) applies

$$P \approx \rho^m c^n \tag{1}$$

i.e. for the relationship of a reference sound power to the sound power on site

$$\frac{P_N}{P} = \left(\frac{\rho_N}{\rho}\right)^m \left(\frac{c_N}{c}\right)^n \tag{2}$$

If air density and speed of sound are expressed as air pressure *B* and temperature *T* (in Kelvin), this leads to

$$\frac{P_N}{P} = \left(\frac{B_N}{B}\right)^m \left(\frac{T_N}{T}\right)^{\frac{n}{2}-m}. \tag{3}$$

The sound power level translated to standard conditions is therefore

$$L_{W,N} = L_W - 10\,m\lg\left(\frac{B}{B_N}\right)dB - 10\left(\frac{n}{2}-m\right)\lg\left(\frac{T}{T_N}\right)dB. \tag{4}$$

In the sound pressure enveloping surface area method, the *in situ* sound power level L_W is replaced by the mean measurement surface sound pressure level, the measurement surface dimension and the natural impedance ratio

$$L_{W,N} = L_P + 10\lg\left(\frac{S}{S_0}\right)dB - 10\lg\left(\frac{\rho c}{(\rho c)_0}\right)dB - 10m\lg\left(\frac{B}{B_N}\right)dB - 10\left(\frac{n}{2}-m\right)\lg\left(\frac{T}{T_N}\right)dB \tag{5}$$

whereby $S_0 = 1\,\mathrm{m}^2$ and $(\rho c)_0 = 400\,\mathrm{N\,s/m^3}$. The impedance level, referred to in ISO 3745 as C_1, can in turn be expressed as a function of air pressure and temperature

$$c_1 = -10\lg\left(\frac{\rho c}{(\rho c)_0}\right)dB = -10\lg\left(\frac{B}{B_0}\sqrt{\frac{T_0}{T}}\right), \tag{6}$$

whereby now the reference values B_0 and T_0 have to be selected in such as way that the reference impedance of $(\rho c)_0 = 400\,\mathrm{N\,s/m^3}$ results from the equation that applies for ideal gases

$$(\rho c)_0 = B_0\sqrt{\frac{\kappa}{R_L T}} \tag{7}$$

with the adiabatic exponent $\kappa = 1{,}402$ and the specific gas constant for air $R_L = 287{,}1\,\mathrm{J/kg/K}$. Equation (5) therefore becomes

$$L_{W,N} = L_P + 10\lg\left(\frac{S}{S_0}\right)dB \underbrace{- 10\lg\left(\frac{B}{B_0}\sqrt{\frac{T_0}{T}}\right)dB}_{C_1} \underbrace{- 10m\lg\left(\frac{B}{B_N}\right)dB - 10\left(\frac{n}{2}-m\right)\lg\left(\frac{T}{T_N}\right)dB}_{C_2} \tag{8}$$

If the sound power in equation. (2) is replaced by the mean measurement surface sound pressure level, the measurement surface and the characteristic impedance, this results in

$$\frac{p_N^2 S_N}{\rho_N c_N}\frac{\rho c}{p^2 S} = \left(\frac{\rho_N}{\rho}\right)^m \left(\frac{c_N}{c}\right)^n \qquad (9)$$

For $S_N = S$, the sound pressure under standard conditions is then

$$p_N^2 = p^2\left(\frac{\rho_N}{\rho}\right)^{m+1} \left(\frac{c_N}{c}\right)^{n+1} \qquad (10)$$

Expressed as a function of air pressure B and temperature T, this results in

$$p_N^2 = p^2\left(\frac{B_N}{B}\right)^{m+1} \left(\frac{T_N}{T}\right)^{\frac{n+1}{2}-m-1} \qquad (11)$$

and the sound pressure level translated to standard conditions is finally

$$L_{p,N} = L_p - 10\,(m+1)\lg\left(\frac{B}{B_N}\right)dB - 10\left(\frac{n+1}{2} - m - 1\right)\lg\left(\frac{T}{T_N}\right)dB\,. \qquad (12)$$

Up to this point, everything is undisputed. There are only discussions regarding the values for the exponents m and n and the reference values B_N and T_N. In ISO/DIS 3745.2,

$$C_1 = -10\lg\left(\frac{B}{B_0}\sqrt{\frac{314{,}15}{273{,}15 + \Theta / °C}}\right)dB \qquad (13)$$

and

$$C_2 = -15\lg\left(\frac{B}{B_0}\frac{296{,}15}{273{,}15 + \Theta / °C}\right)dB \qquad (14)$$

are used with $B_0 = 1{,}01325 \cdot 10^5$ Pa. A comparison of equations (13) and (14) with equation (8) now results in $B_N = B_0 = 1.01325 \cdot 10^5$ Pa, $m = 1.5$, $n = 0$ and $T_N = 296.15$ K. In order to achieve homogeneity, these values should also be retained for the ISO 11200 series. However, I am unsure whether the same values are also contained in the FDIS of ISO 3745.

This means equation (12) results in the correction for the emission sound pressure level

$$\boxed{L_{p,N} = L_p - 25\lg\left(\frac{B}{B_N}\right)dB + 20\lg\left(\frac{T}{T_N}\right)dB}. \qquad (15)$$

Appendix 3 The simulation of machine emissions

Range of application and limits of the method

Within the framework of this investigation, the machine emission as well as the sound propagation related to the free sound field is simulated with a computer program /21/.

The purpose of this simulation calculation is to calculate the sound pressure level at a specified position from the simulated machine structure with its source distribution.

A calculation of this nature does not involve the description of construction-related propagation paths and force flows in the machine structure or their dynamic characteristics, rather already presupposes sound sources that can be described with sound power levels. With the starting point 'sound power level', it makes no sense to take account of phase relation and phenomena caused by interference, as done e.g. in /22/. It is much more important to simulate the machines in their physical expansion in such a way that the redistribution of the sound energy on the way from the emission areas to the specified position are described to an adequate degree of correctness, including reflection and screening.

Observing the machine groups that are of interest here also shows that the sound proportions emitted from the different source areas at the same machine are to be regarded in most cases as incoherent with regard to superposition at the observation point.

The limits of the method result directly from the strategies applied in the calculation and the approximations this implies. Due to the fundamental significance of this simulation technique for continued standardization in the field of machine noise emissions, it will be explained briefly in the following.

The machine structures themselves are arrangements of cubics, cylinders of any type with polygon base surfaces, regular cylinders as well as vertical plates.
The structures can

- emit sound
- reflect sound
- absorb sound
- shield or diffract sound.

The basis of all source arrangements is the point source. It is characterized by the sound power level related to frequency bands or the total sound power level as well as, if applicable, directional characteristics. The sound proportions emitted by different point sources are regarded as incoherent. (This means that maximum and minimum sound pressure levels in the case of emission from a hydraulic tank excited by flexible shafts cannot be found using this technique).

In the case of sound propagation from the source to immission point, the following section takes account of the geometric divergence attenuation, the air absorption attenuation, the solid angle index to describe the ground reflection according to relationship (11) of ISO 9613-2 as well as the barrier attenuation for all structures that prevent direct propagation. For the purpose of machine simulation these attenuation measures are described according to ISO 9613-2 /12/ section (6). The computing steps that are important will be described briefly in the following.

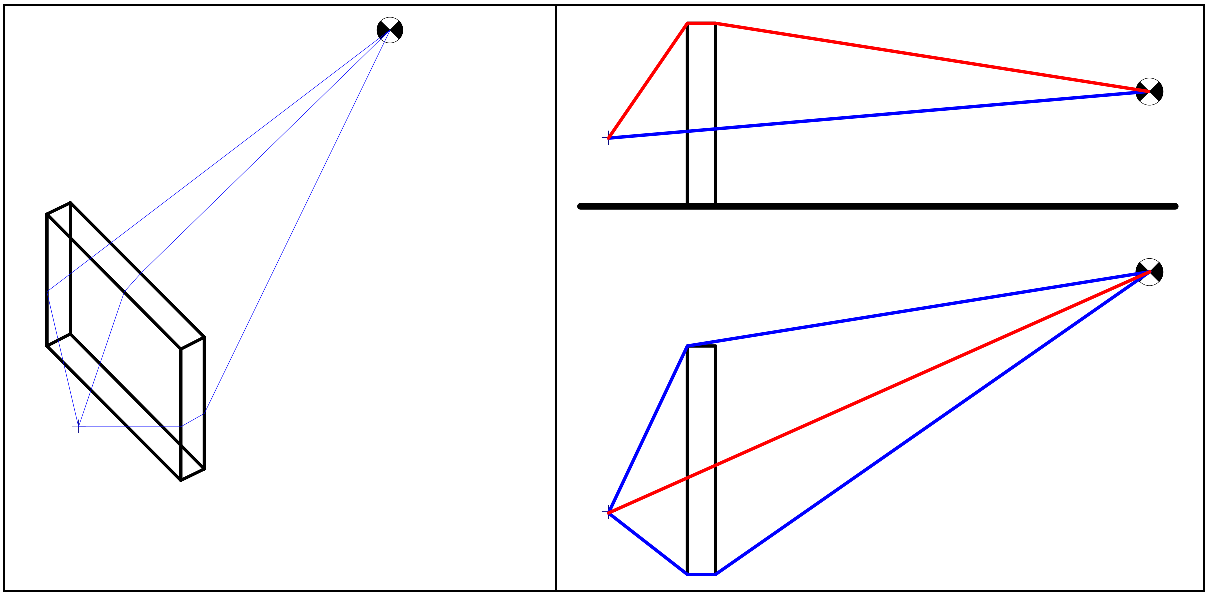
It should be noted that the application of computing methods according to ISO 9613-2 for treatment of the sound propagation in the vicinity of machines requires a certain modeling technique. For example, a machine must be simulated by larger, actually reflecting and screening objects such as plates and cubics. Modeling that is too detailed with objects in the scale of the characterizing wavelengths is to be avoided.

Screening

If objects are located in the emission path, their screening effect is taken into account by means of a corresponding barrier attenuation.

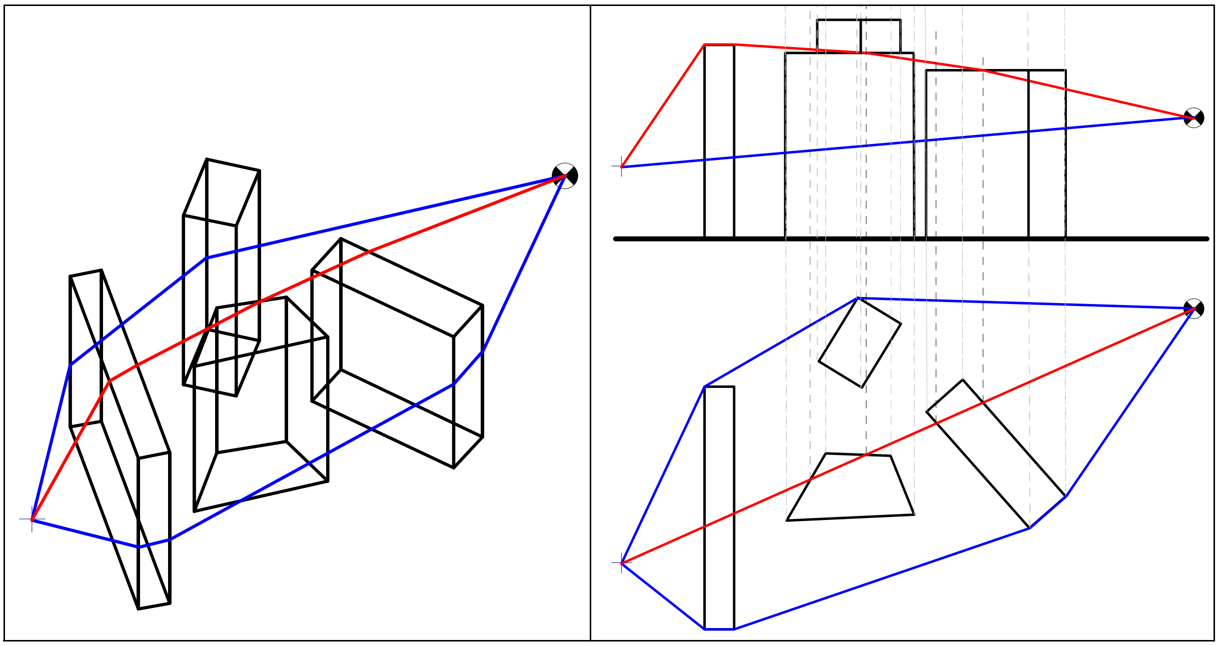
Calculation of this barrier attenuation is according to equations (14)-(16) in section 7.4 of ISO 9613-2, based on Maekawa.

Generally three contributions of diffracted sound energy are taken into account as shown in Appendix 3, Fig. 1.



Appendix 3, Fig. 1 The three rays taken into account in the screening calculation with one object

If a number of objects are located in the emission path, also three contributions each are taken into account for each pair source – immission point.



Appendix 3, Fig. 2 The three diversions taken into account in the screening calculation with several objects

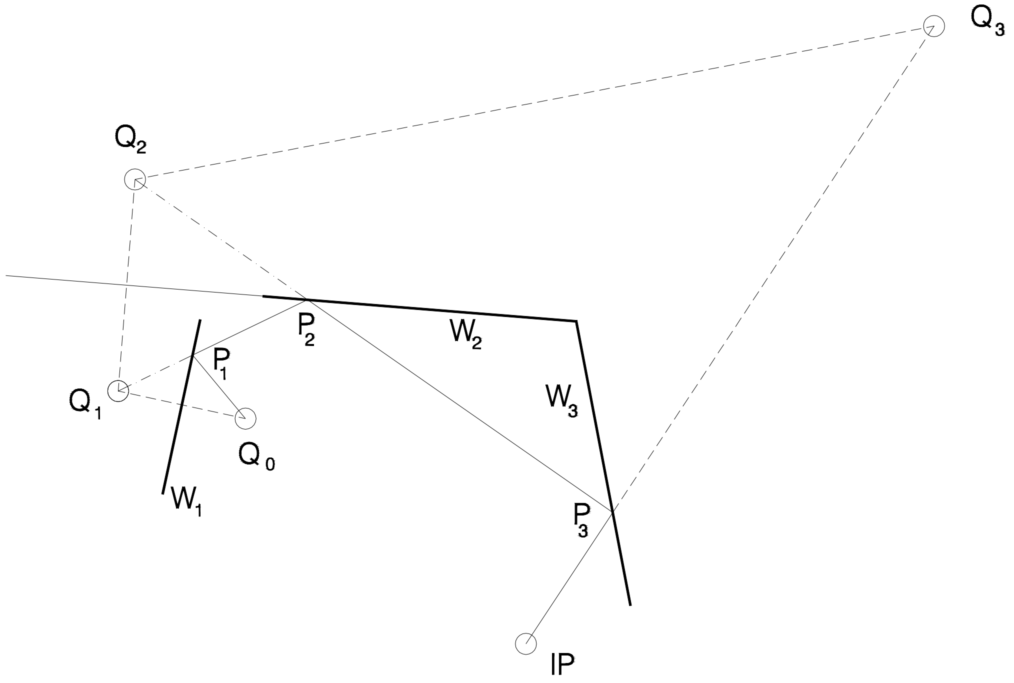
This method shown in Appendix 3, Fig. 2, for a number of objects, in which the lateral diffraction is formed with the two beams of the convex envelope, is an approximation. There are indeed a large number of other emission paths through the labyrinth of objects, whereby these paths can even determine the level in special cases. The described method, however, taking account of the computing time effort that is still available and the mean achievable accuracy, has turned out to be an optimized compromise. For calculation involving a great deal of computing time with large objects, the lateral diffraction can be disabled – in this case, exclusively the emission path via the upper edges is taken into account.

As a rule, for simulation of the machine emission, lateral diffraction must be expected. Due to the small dimensions of screening objects, neglecting the lateral diffraction would lead to an overestimation of the screening effect.

Reflection

All objects (cubics, regular cylinders, cylinders with polygon base surfaces and vertical plates) can be defined as reflecting. Their surface can be assigned a degree of absorption or reflection as a single-figure value or as a spectrum.

The reflection calculation uses the mirror source method, i.e. additional mirror sound sources are taken into account for all possible emission paths up to an order that can be specified.



Appendix 3, Fig. 3 Construction of a reflection of the 3rd order according to the mirror source method

Appendix 3, Fig. 3 shows the construction of a ray of the 3rd order with sound propagation from the source Q_0 to immission point IP.
For the ray $Q_0 – P_1 – P_2 – P_3 –$ IP,

$$P = P_0 \cdot (1-\alpha_1)\cdot(1-\alpha_2)\cdot(1-\alpha_3)$$

is assumed as mirror source sound power, whereby P_0 is the actual emitted sound power of the source Q_0 and α_n is the degree of absorption of the surface area W_n at the point P_n. (The computing program can be used to calculate for all objects with flat outer surfaces reflections of up to the 20th order in full. In the case of regular cylinders, exclusively reflection of the 1st order is calculated).

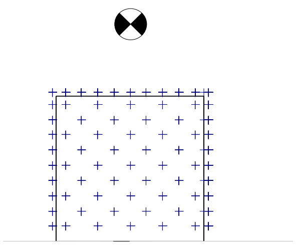
Objects are only included as reflecting in the calculation if the dimensions of their projection related to the wavelength exceed a given value in the emission direction. With the simplified calculation with A sound pressure levels, the frequency of 500 Hz is assumed.

For the acoustical machine simulation it is necessary to calculate up to high reflection orders if the machine geometry is complex (e.g. with enclosure at all sides but with open and therefore free radiating deck). Otherwise the radiated sound power would be underestimated.

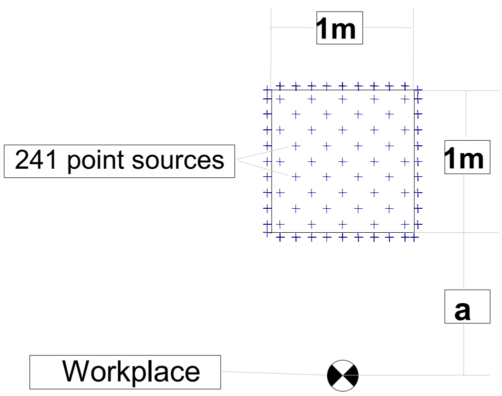
Emission

A sound-emitting body is modeled by simulating its shape with the described objects (cubics, any cylinders with polygon base surface, regular cylinders as well as vertical plates). The sound emission of the outer surfaces is simulated by covering the surface with point sources that are arranged on a regular grid (2 cm for the investigations described here).

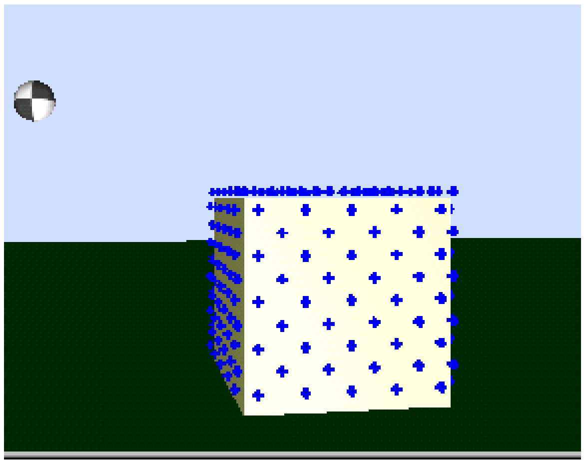
The representations in Appendix 3, Fig. 4 to Fig. 6 show the model of a machine cube created in the computing program with dimensions 1 m / 1 m / 1 m, emitting sound with all sides.



Appendix 3, Fig. 4
Front view of the machine cube



Appendix 3, Fig. 5
Ground view of the machine cube

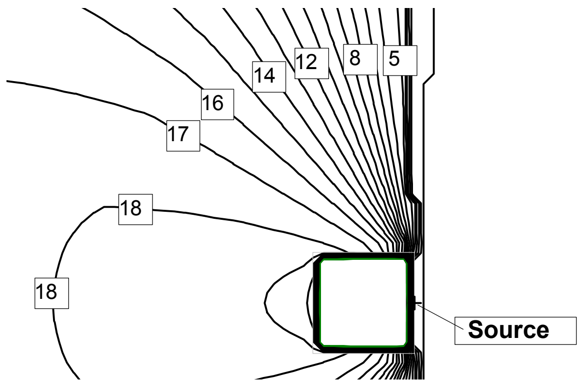


Appendix 3, Fig. 6
3D view of the machine cube emitting on all sides

The emission in the half-space is achieved in that the sound emitted from the point sources is reflected on the own machine structure. In the example shown, this means each point source shown and also a mirror sound source at a distance of 4 cm are included in the calculation.

In determining the level contribution caused by a point source at an immission point, the structure of the machine cubic as self-screening is included in the calculation. Here, all three of the influences described above are taken into account. The mirror sound source radiates only into half space in front of the radiating surface – the calculation of the mirror source in the area screened by the machine itself is rejected due to the reflection check.

If a point source positioned in the side surface center of the described machine cubic is examined, the self-screening leads to the distribution of barrier attenuation as shown in diagram Appendix 3, Fig. 7. They were calculated as a difference without and with the machine cubic.



Appendix 3, Fig. 7 The barrier attenuation calculated with a machine structure 1 m / 1 m /1 m and a point source on the side surface

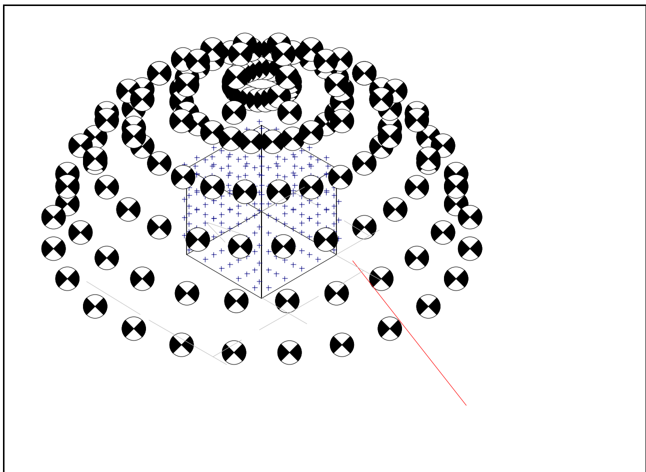
Larger sound-emitting surface can also be simulated by arranging corresponding area sources instead of the arrangement of point sources. Depending on the distance of the immission point, these are dynamically subdivided into such small surface elements that they in turn can be replaced in the calculation by point sources with the same sound power. This method of dynamic raster scanning leads to higher computing speeds, because at greater distances larger elements are used.

Simulation of determining the sound power level using the enveloping surface area method (model check)

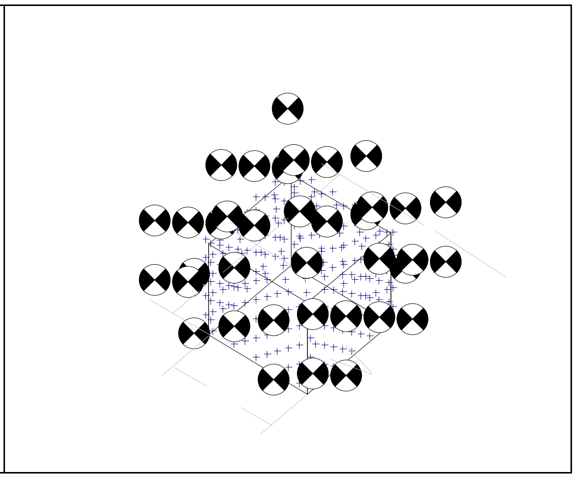
For the planned examination of standard methods with numerical simulation, the sound sources at the machine are assigned their sound power and the sound pressure level caused by this machine at the specified position or at the allocated workplace is calculated. As will be shown, the difference between sound power level and emission sound pressure level is an important parameter for assessing of the accuracy that can be achieved with a certain standard measuring method on the relevant machine type.

As the energetic total of all the sound power levels assigned to the sources of a machine is used as the machine sound power level, it must be ensured that the combination of all the described operations such as self-screening and reflection means that exactly the total assigned sound power levels becomes effective.

This check is run by simulating the measurement of the sound power level using the enveloping surface area method.



Appendix 3, Fig. 8
Semi-spherical measurement surface area



Appendix 3, Fig. 9
Cubic measuring surface

To achieve this, the coordinates of the immission points on the 'measurement surface' are calculated externally in a spreadsheet. These values are imported across an ODBC interface into the simulation program and the corresponding immission points are generated. The semi-spherical and cubic arrangements shown in the diagrams Appendix 3, Fig. 8 and Appendix 3, Fig. 9 were created in this way.

For the sound propagation calculation with the simulation program, the proportional sound pressure level of each point source at each individual immission point of the 'measurement surface' is calculated and totaled. The results table with the calculated level values is now copied into a spreadsheet once again and the level values Lj and the surface area proportion of the measurement surface Sj assigned to each measuring point is used with

$$L_W = 10 \cdot \log\left(\sum_j S_j \cdot 10^{0.1 \cdot L_j}\right) dB$$

to calculate the sound power level. Within the framework of the accuracy associated with the shape of the measurement surface due to the angle error, this sound power level must match the total sound power level of all individual sources at the machine.

This 'calibration' was carried out on all included machine models. With this part of the investigation, the program settings required for an exact simulation were determined.

It should be noted that the simulation of both the machine emission and the measurement of the sound power level according to the enveloping surface area method is very suitable for examining and assessing machine-specific specifications for suitable arrangement or other influences. For example, it is possible without additional effort to arrange reflecting objects or walls alongside the measurement surface and to determine the apparent increase in the determined sound power level this causes.

The following example shows the result of a simulation calculation of this nature – shown in a uniform manner as a machine sheet. Sheets of this nature have been created for a number of machine types – they can be a valuable aid in deciding on the measuring method for specific machines.

Appendix 4 Machine Sheet 26

Machine 5 m / 1 m / 2 m
(M_5qh_1_2.cna)

Sound power level 100 dB(A)

At the back, 1 source with 100 dB(A)

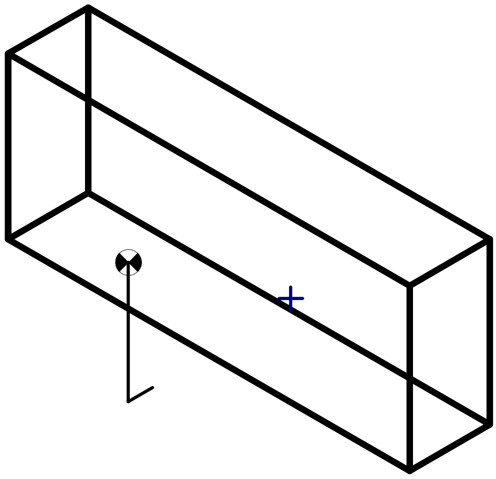
Workplace on the longitudinal side at 1.5 m height at distance 0.5, 1 and 2 m

Calculated emission sound pressure level in dB(A):

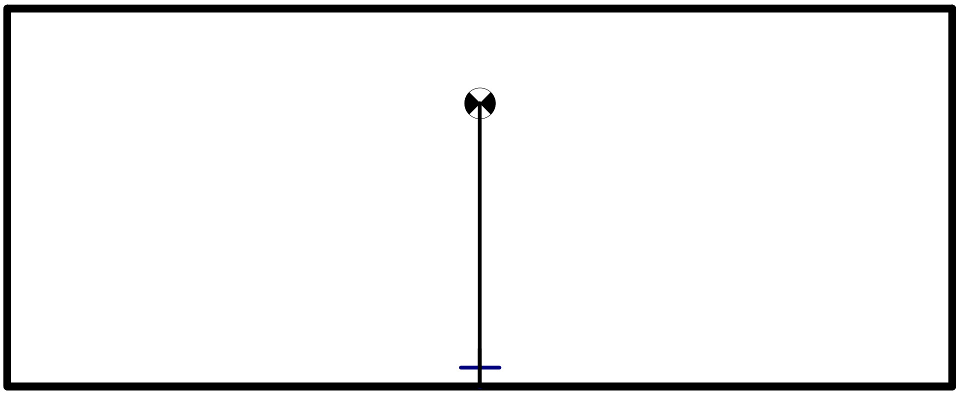
0.5 m / 70.9, 1 m / 69.6, 2 m / 67.1

Results $L_{W\text{-}p}$ in dB:
0.5 m / 29.1, 1 m / 30.4, 2 m / 32.9

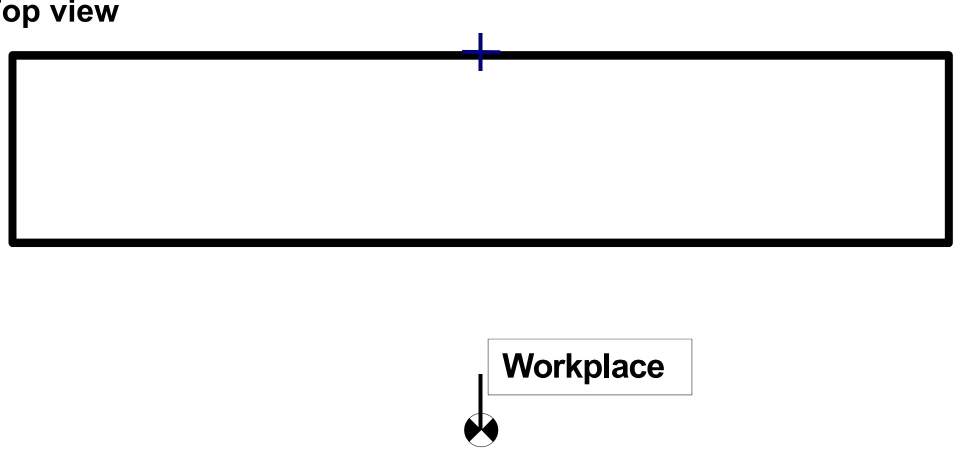
Oblique view



Frontal view



Top view

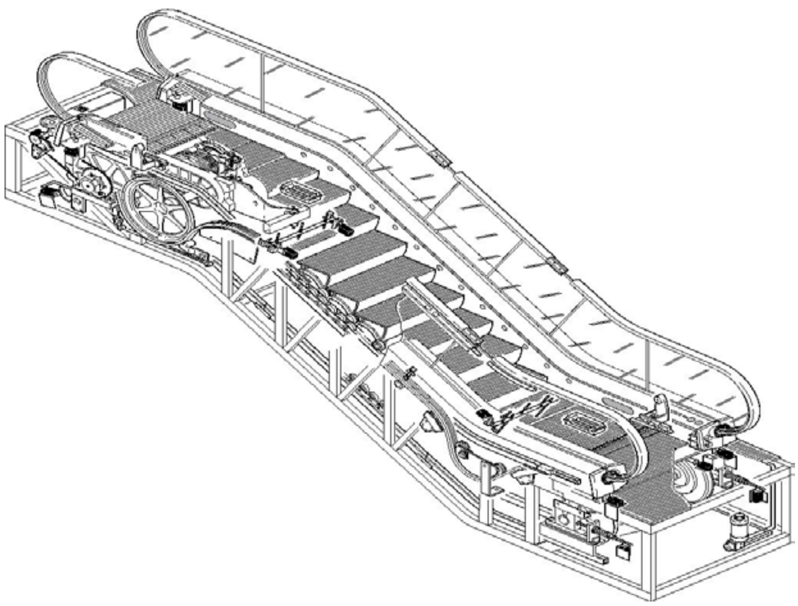


Appendix 5 Proposal for determining the noise emission of escalators

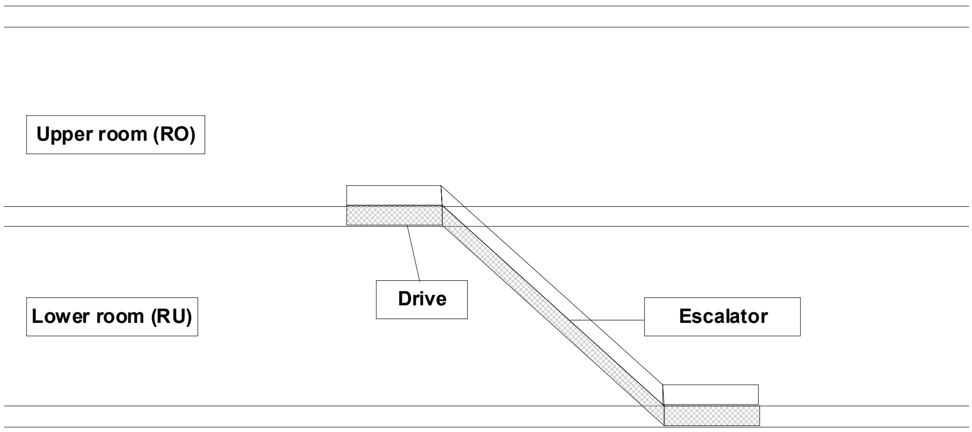
Task definition

A typical example in which a number of methods of determining the emissions are to be combined in order to obtain acceptable measuring methods is determining the emission sound pressure level of escalators. The task definition resulted from an inquiry from a corresponding NALS study group - the solution sketched in the following section has not yet been implemented and is to be viewed only as an experts proposal.

Appendix 5, Fig. 1 System of escalators in a department store



Appendix 5, Fig. 2 Design of an escalator



Appendix 5, Fig. 3 Scheme of escalator installation

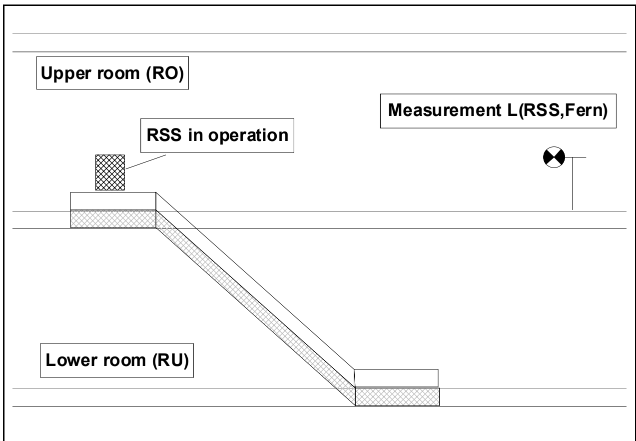
The illustrations Appendix 5, Fig. 1 to 3 show the difficulty in determining the noise emission. The escalator connects two floors, whereby sound power is emitted into each of these floors. As the measurement is to be possible *in situ* – i.e. with the escalator installed - the sound power level and emission sound pressure level are to be ascertained separately in both floors, RU and RO.

Determining the sound power level

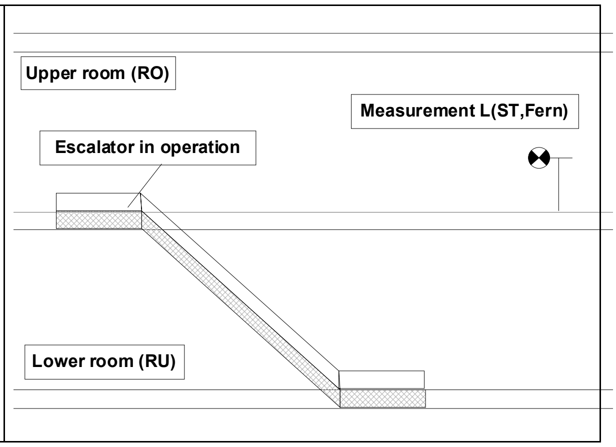
In principle, this can be determined according to ISO 3744/46, ISO 3747 using the sound pressure method and ISO 9614 using the sound intensity method. As the escalator is an extended source with relatively difficult geometry, the enveloping surface area methods are expensive/complex.

For this reason, determining the sound power level based on ISO 3747 according to a reference method is proposed.

The sequence is as follows:



Appendix 5, Fig. 4 Measurement of $L_{RSS,Fern}$



Appendix 5, Fig. 5 Measurement of $L_{ST,Fern}$

A reference sound source with known sound power level must be available – this sound power level is $L_{W,RSS}$.

1. Measurement of the sound pressure level during operation of the reference sound source -> $L_{RSS,Fern}$
2. Measurement of the sound pressure level during operation of the escalator -> $L_{ST,Fern}$
3. Determining the sound power level of the escalator emitted into the room

$$L_{W,ST} = L_{W,RSS} + L_{ST,Fern} - L_{RSS,Fern} \quad (1)$$

In the same way, the sound power level in the lower room RU is measured.

Determining the emission sound pressure level

Determining the emission sound pressure level was based on a new proposal for ISO 11204. The environmental correction is ascertained according to

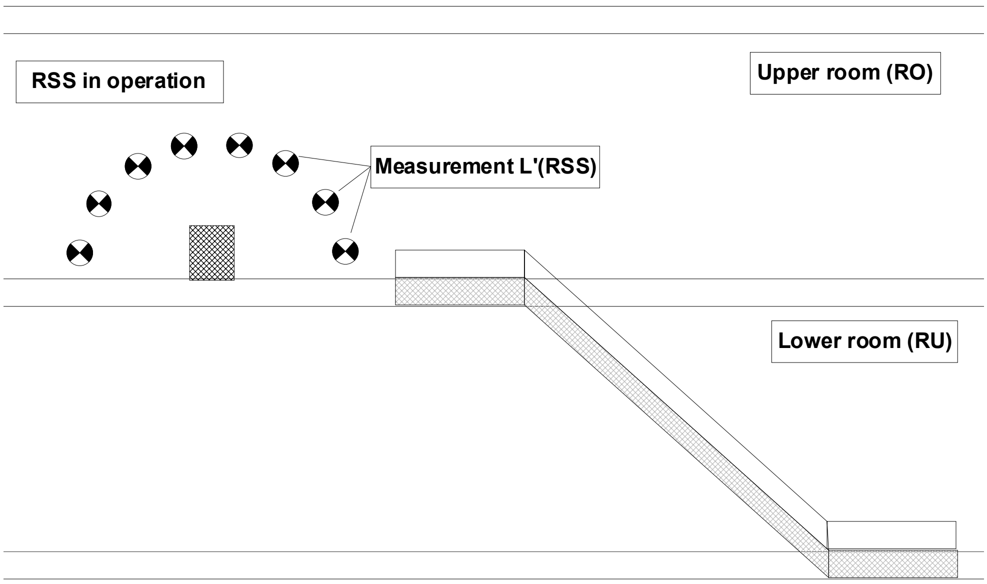
$$K_3 = -10 \cdot \lg\left(1 - \frac{4 \cdot A_0}{A} \cdot 10^{0,1(L_{W,ST} - L'_p)}\right) dB \quad (2)$$

with

A Equivalent absorption area in m²
A_0 Reference value of the equivalent absorption area (= 10 m²)
$L_{W,ST}$ Sound power level of the source (source under test)
L'_p Sound pressure level at the specified workplace measurement point not corrected by the influence of the room

For this correction, A and $L_{W,ST}$ of the source must be known.
$L_{W,ST}$ is determined according to the above-mentioned method with the reference sound source. As a rule, this involves flat rooms with complicated room geometry, so A was also to be determined using the reference sound source.

Determining A:
This method is described in section 2.3. According to Appendix 5, Fig. 6, with extraneous sources switched off, the reference sound source is operated and the mean sound pressure level $\overline{L}'$ is determined on a half sphere measurement surface.

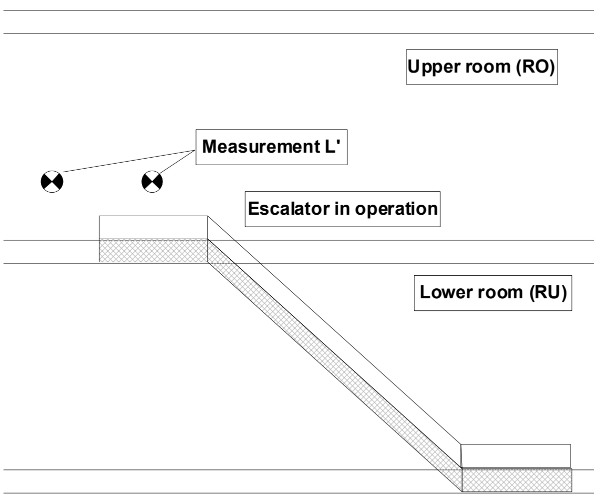


Appendix 5, Fig. 6 Determining the equivalent absorption area by measurement with reference sound source

With the surface area S of the half sphere, the equivalent absorption area results in

$$A = \frac{4 \cdot S_{RSS}}{\frac{S_{RSS}}{S_0} \cdot 10^{0,1 \cdot (\bar{L}'_{RSS} - L_{W,RSS})} - 1} \qquad (3)$$

Measurement of the sound pressure level at the specified position (workplace):
The sound pressure level is now measured at the agreed workplace point with the escalator in operation.



Appendix 5, Fig. 7 Measurement of the sound pressure level at the agreed points

Determining the environmental correction K_3 for each agreed point:
In the first step, the value z is determined.

$$z = 1 - \frac{4 \cdot A_0}{A} \cdot 10^{0,1\left(L_{W,ST} - L'_p\right)} \tag{4}$$

In the second step, K3,j at point j results from

$$K_{3,j} = \begin{matrix} 7 & \text{for } z \leq 0.2 \\ -10 \cdot \lg(z) & \text{for } 0.2 < z \leq 1 \\ 0 & \text{for } z > 1 \end{matrix} \tag{5}$$

If z is lesser than or equal to 0.2, it should be specified that the environmental correction K_3 is at least 7 dB.

Determining the emission sound pressure level:
The emission sound pressure level at point j then results from

$$\underline{L_{p,j} = L'_{p,j} - K_{3,j}} \tag{6}$$

Combined method for determining the emission sound pressure level:
If the sound power level is not required as a separate emission parameter, its determination as an intermediate step can also be omitted. To do so, (1) and (3) are inserted in (2), which means that K_3 is determined directly from the measured variables:

$$K_3 = -10 \lg \left[1 - \left(10^{0,1\left(\overline{L}'_{RSS} - L_{W,RSS}\right)} - \frac{S_0}{S_{RSS}} \right) \cdot 10^{0,1\left(L_{W,RSS} + L_{ST,Fern} - L_{RSS,Fern} - L'_p\right)} \right] dB \tag{7}$$

In practice, it is initially the variable

$$z = 1 - \left(10^{0,1\left(\overline{L}'_{RSS} - L_{W,RSS}\right)} - \frac{S_0}{S_{RSS}} \right) \cdot 10^{0,1\left(L_{W,RSS} + L_{ST,Fern} - L_{RSS,Fern} - L'_p\right)} \tag{8}$$

that is to be determined and with this then from (5) the environmental correction K_3. The emission sound pressure level then results from (6).