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पावर ट्रांसफार्मर

भाग 10 ध्वनि स्तर का निर्धारण

(पहला पुनरीक्षण)

Power Transformers

Part 10 Determination of Sound Levels

(First Revision)

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भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुर शाह ज़फर मार्ग, नई दिल्ली - 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI - 110002
www.bis.gov.in www.standardsbis.in

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NATIONAL FOREWORD

This Indian Standard (Part 10) (First Revision) which is identical to IEC 60076-10 : 2016 'Power transformers — Part 10: Determination of sound levels' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Transformer Sectional Committee and approval of the Electrotechnical Division Council.

This standard was first published in 2009. This revision has been undertaken to align with the latest version of IEC 60076-10 : 2016.

This standard is published in various parts. Other parts in this series are:

Part 1	General
Part 2	Temperature-rise
Part 3	Insulation levels, dielectric tests and external clearances in air
Part 4	Terminal markings, tappings and connections
Part 5	Ability to withstand short circuit
Part 6	Reactors
Part 7	Loading guide for oil-Immersed power transformers
Part 8	Application guide
Part 10/Sec 1	Determination of sound levels, Section 1 Application guide
Part 11	Dry-type transformers
Part 12	Loading guide for dry-type power transformers
Part 14	Liquid-immersed power transformers using high-temperature insulation materials
Part 15	Gas-filled power transformers
Part 16	Transformers for wind turbine applications
Part 18	Measurement of frequency response
Part 19	Rules for the determination of uncertainties in the measurement of the losses on power transformers and reactors
Part 21	Standard requirements, terminology and test code for step-voltage regulators

The text of IEC standard has been approved as suitable for publication as an Indian Standard without deviations. Certain terminologies and conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker, while in Indian Standards the current practice is to use a point (.) as the decimal marker.

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INTRODUCTION

One of many parameters considered when specifying, designing and placing transformers, reactors and their associated cooling devices is the sound level that the equipment is likely to emit under defined in-service conditions. This part of IEC 60076 provides the basis for the specification and test of sound levels.

This standard describes in a logical sequence the loading conditions, how to specify and to test as well as how to evaluate and report sound levels for the equipment under test. A new section for the specification of sound levels has been introduced as Clause 5.

For the purpose of this standard, the definition "distribution type transformers" was introduced. This reflects industry's need to maintain simpler and faster sound measurements for this category of transformers.

The new requirement for reporting 1/3-octave band spectra for all sound levels (including the background noise) on units for installation in substations reflects the more onerous conditions imposed by planning authorities on the purchaser and also the improved functionality of modern instrumentation.

When the sound intensity method was introduced in this standard limited experience was available. During subsequent years of operating this standard levels of experience have significantly increased and necessary changes have become evident. The equivalence of the pressure and the intensity methods has been demonstrated within certain test limitations.

The introduction of new validation criteria for the intensity method recognises these limitations. The permissible pressure – intensity index ΔL remains 8 dB however the difference between measured sound pressure level and reported sound intensity level is limited to 4 dB.

For the pressure method the correction procedure for reflections has been enhanced by recommending the application of frequency dependent K values derived by measurement of the reverberation time of the test facility. Where K is derived from absorption coefficients the table for the average absorption coefficients has been rationalised to represent surfaces likely to be found in the working environment.

Walk-around procedure and point-by-point procedure are equally applicable. The walk-around procedure reflects the evolution of working practice allowing more time efficient measurements mainly on large units. For distribution type transformers and in special situations (health and safety) the point-by-point procedure is more appropriate.

In order to mitigate near-field effects the preferred measurement distance is set to 1 m with exceptions for distribution type transformers, small test facilities, situations with low signal-to-noise ratio and for health and safety where the distance is maintained at 0,3 m.

One single formula for the calculation of the measurement surface area S has been introduced because the former complexity could only result in differences always smaller than 1 dB.

All figures describing the measurement surface area have been revised to be in accordance with the enveloping method for sound power determination. The height h is always measured from the test facility floor regardless of the height of the supports beneath the test object unless the test object is mounted on a support with a sufficiently large surface acting as reflecting plane.

Additional figures explain the procedure for the determination of the measurement surface area and the prescribed contour for a number of configurations of dry-type reactors.

When using this standard, it is recommended to frequently refer to the corresponding application guide IEC 60076-10-1:2016 as it promotes understanding with important background information and helpful details. IEC 60076-10 and IEC 60076-10-1 were revised in parallel by the same maintenance team resulting in fully aligned documents.

Indian Standard

POWER TRANSFORMERS

PART 10 DETERMINATION OF SOUND IEVELS

(First Revision)

1 Scope

This Part of IEC 60076 defines sound pressure and sound intensity measurement methods from which sound power levels of transformers, reactors and their associated cooling devices are determined.

NOTE For the purposes of this standard, the term "transformer" frequently means "transformer or reactor".

The methods are applicable to transformers, reactors and their cooling devices – either fitted to or separate from the transformer – as covered by the IEC 60076 and IEC 61378 series.

This standard is primarily intended to apply to measurements made at the factory. Conditions on-site can be very different because of the proximity of objects, including other transformers. Nevertheless, this standard is applied to the extent possible for on-site measurements.

2 Normative references

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

IEC 60076-1:2011, *Power transformers – Part 1: General*

IEC 60076-8:1997, *Power transformers – Part 8: Application guide*

IEC 61043:1993, *Electroacoustics – Instruments for the measurement of sound intensity – Measurements with pairs of pressure sensing microphones*

IEC 61672-1, *Electroacoustics – Sound level meters – Part 1: Specifications*

IEC 61672-2, *Electroacoustics – Sound level meters – Part 2: Pattern evaluation tests*

ISO 3382-2:2008, *Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms*

ISO 3746:2010, *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Survey method using an enveloping measurement surface over a reflecting plane*

ISO 9614-1:1993, *Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 1: Measurement at discrete points*

ISO 9614-2:1996, *Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 2: Measurement by scanning*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60076-1, as well as the following, apply.

3.1
sound pressure
p
fluctuating pressure superimposed on the static (barometric) pressure by the presence of sound

Note 1 to entry: It is expressed in pascal, Pa.

3.2
sound pressure level
L_p
ten times the logarithm to the base 10 of the ratio of the square of the r.m.s. sound pressure to the square of the reference sound pressure (p_0 = 20 × 10^{-6} Pa)

Note 1 to entry: It is expressed in decibels, dB.

$$L_p = 10 \times \lg \frac{p^2}{p_0^2} \quad (1)$$

3.3
sound intensity
I
vector quantity describing the magnitude and direction of the sound power flow per unit area at a given position

Note 1 to entry: The unit is watts per square metre, W/m^2.

3.4
normal sound intensity
I_n
component of the sound intensity in the direction normal to a measurement surface

Note 1 to entry: By convention, normal sound intensity is counted positive if the energy flow is directed away from the test object and negative if the energy flow is directed towards the test object.

3.5
normal sound intensity level
L_I
ten times the logarithm to the base 10 of the ratio of the r.m.s. normal sound intensity to the reference sound intensity (I_0 = 1 × 10^{-12} Wm^{-2})

Note 1 to entry: It is expressed in decibels, dB.

$$L_I = 10 \times \lg \frac{|I_n|}{I_0} \quad (2)$$

Note 2 to entry: Since I_n can be either positive or negative, a separate direction flag F_{Dir} for L_I to indicate the direction of flow of energy is to be maintained for further analysis such as calculating average and integral quantities.

3.6
direction flag
F_{Dir}
indication for the direction of sound energy flow, required for sound intensity because of its vector nature

Note 1 to entry: +1 for sound energy flow away from the test object, –1 for sound energy flow towards the test object.

3.7
sound power
W
rate at which airborne sound energy is radiated by a source

Note 1 to entry: It is expressed in watts, W.

3.8
sound power level
L_W
ten times the logarithm to the base 10 of the ratio of a given r.m.s. sound power to the reference sound power ($W_0 = 1 \times 10^{-12}$ W)

Note 1 to entry: It is expressed in decibels, dB.

$$L_W = 10 \times \lg \frac{W}{W_0} \tag{3}$$

3.9
total sound level
sound level comprising the whole frequency range under consideration

Note 1 to entry: This level is returned either directly by the measurement device or derived by logarithmic summation of the sound levels of all individual frequency bands.

3.10
principal radiating surface
hypothetical surface surrounding the test object, assumed to be the surface from which sound is radiated

3.11
measurement surface
S
surface enveloping the test object at the measurement distance from the principal radiating surface on which the measurement path(s) or points are located

3.12
surface measure
L_S
ten times the logarithm to the base 10 of the ratio of the measurement surface S to the reference surface S_0 (1 m^2)

Note 1 to entry: It is expressed in decibels, dB.

$$L_S = 10 \times \lg \frac{S}{S_0} \tag{4}$$

3.13
measurement distance
x
horizontal distance between the principal radiating surface and the measurement surface

3.14
prescribed contour
horizontal path(s) on the measuring surface on which measurements shall be made

3.15
walk-around procedure
sound level measurement obtained by continuously moving the microphone(s) along the prescribed contour(s) at constant walking speed as the device is measuring a time averaged and spatially averaged sound level

Note 1 to entry: Test equipment may record a digital audio file during the measuring procedure for post-processing to determine the necessary quantities.

3.16
point-by-point procedure
sound level measurements obtained from a number of discrete microphone positions on the prescribed contour(s), equally spaced and not more than 1 m apart

Note 1 to entry: The spatial average sound level is the average of all the point measurements.

3.17
background noise level
A-weighted sound pressure level measured along the prescribed contour with the test object inoperative

3.18
environmental correction
K
correction that accounts for the influence of undesired sound reflections from room boundaries and/or reflecting objects in the test room when sound pressure measurements are used

3.19
P-I index
ΔL
difference between uncorrected spatially averaged sound pressure level and spatially averaged sound intensity level

Note 1 to entry: A-weighted values shall be used.

3.20
distribution type transformers
transformers for installation other than in substations with rated power typically lower than 5 000 kVA

Note 1 to entry: This definition is made for the purpose of this standard.

Note 2 to entry: This definition applies to both liquid-immersed and dry-type transformers.

4 Sound power for different loading conditions

4.1 General

There are three components of sound potentially contributing to the overall transformer sound power level in service:

- sound power at no-load excitation;
- sound power of the cooling device;
- sound power due to load current.

The representation of the sound power level of a transformer at a certain service condition is given by the logarithmic sum of the three sound power components at this service condition. For details see Clause 13.

4.2 Sound power at no-load excitation

Sound power due to no-load excitation has to be regarded for all types of transformer. The excitation voltage shall be of sinusoidal or practically of sinusoidal waveform and rated frequency. The voltage shall be in accordance with 11.5 of IEC 60076-1:2011. In the case of reactors a no-load condition does not exist since rated current will flow as soon as rated voltage is applied. For more information on reactor sound testing see IEC 60076-6.

The usual condition for sound power level determination of transformers at no-load excitation refers to rated voltage at an untapped winding. Other excitation conditions may occur in service leading to lower or higher sound power levels and might also be the condition for a guarantee and if so shall be specified by the purchaser. For transformers designed to operate with variable flux, the sound power at no-load excitation is strongly impacted by the tapping position. The tapping position for the sound measurement has therefore to be agreed between manufacturer and purchaser during tender stage.

If a transformer is fitted with reactor-type on-load tap-changer equipment where the reactor may on certain tap-changer positions be permanently energized, the measurements shall be made with the transformer on a tapping which involves this condition and which is also as near to the principal tapping as possible.

The selected test conditions shall be clearly indicated in the test report.

NOTE DC bias magnetization of the core can cause a significant increase in the measured sound levels. Its presence is indicated by the existence of odd harmonics of the excitation frequency in the sound spectrum and this can be identified by a narrow band analysis. The DC bias impact on no-load sound level measurements during factory testing can be practically eliminated by an over excitation run for some minutes. When over excitation is not a practical option, as in on-site measurements, DC bias elimination after a transformer inrush event can take several hours or even days.

4.3 Sound power of the cooling device(s)

The usual condition for sound power level determination is to have all cooling devices necessary to operate the transformer at its rated power running.

In case of a water cooling device, the water flow need not be maintained during sound level testing.

In case of variable speed cooling devices (usually fans) the speed during sound level testing has a significant effect on the sound power level. The speed of the cooling device selected for the sound level measurement shall be the speed necessary to operate the transformer at its rated power under the most onerous external cooling medium conditions.

The selected test conditions shall be clearly indicated in the test report.

4.4 Sound power due to load current

The main component of the sound power level due to load current, for most transformers, is of double the power frequency.

The magnitude of the load current sound power level can be roughly estimated by Equations (5) and (6):

$$L_{\mathrm{WA,\,Ir}} \approx 39 + 18 \times \lg \frac{S_{\mathrm{r}}}{S_{\mathrm{p}}} \text{ for 50 Hz power frequency} \tag{5}$$

$$L_{\mathrm{WA,\,Ir}} \approx 44 + 18 \times \lg \frac{S_{\mathrm{r}}}{S_{\mathrm{p}}} \text{ for 60 Hz power frequency} \tag{6}$$

where

$L_{\mathrm{WA,Ir}}$ is the estimated A-weighted sound power level of the transformer at rated current and rated frequency at short-circuit condition;

S_{r} is the rated power in MVA;

S_{p} is the reference power (1 MVA).

For auto-transformers and three winding transformers, the equivalent two-winding rated power is used instead of S_{r}, in accordance with 3.2 of IEC 60076-8:1997.

NOTE 1 The predictions with Equations (5) and (6) are usually within ±6 dB of the measured sound power level due to rated load current.

A guideline to estimate the significance of the sound power due to load current is given by Equations (5) and (6). When the calculated values are 10 dB or more below the sound power level estimated at no-load excitation, its contribution will be negligible and therefore need not be tested, unless the purchaser has specified the test.

NOTE 2 Distribution type transformers usually do not require consideration of sound power due to load current.

When this measurement is required, one winding shall be short-circuited and the rated current at rated frequency shall be injected into the other winding.

Unless otherwise specified, the tests shall be carried out with the tap-changer (if any) on the principal tapping. However, this tap position may not give the maximum sound level in service due to variations of the magnetic stray field distributions in the windings, the core and the tank shielding elements.

The selected test conditions shall be clearly indicated in the test report.

The sound power level at a current different from the rated current can be calculated by Equation (7):

$$L_{\mathrm{WA,\,IT}} = L_{\mathrm{WA,Ir}} + 40 \times \lg \frac{I_{\mathrm{T}}}{I_{\mathrm{r}}} \tag{7}$$

where

$L_{\mathrm{WA,Ir}}$ is the calculated or measured A-weighted sound power level at rated current;

$L_{\mathrm{WA,IT}}$ is the calculated A-weighted sound power level at actual current;

I_{r} is the rated current;

I_{T} is the actual current.

The equation is valid for currents in the range of 60 % to 130 % of rated current. It shall also be applied to calculate the sound power level due to rated load current if, in case of test bay limitations, testing is agreed to be done at a current lower than rated current.

In service, the direction of load flow and the power factor can impact the sound power level due to a superposition of the flux at no-load condition and the stray flux partly entering the core. This effect cannot be replicated by factory testing.

Special transformers such as industrial, SVC and HVDC converter transformers as well as specific types of reactor experience load currents with high harmonic content and subsequently produce sound harmonics of higher frequency. The injection of such currents requires special test equipment and test configurations which usually are not available for transformer testing. For reactors such tests are more common, see IEC 60076-6. Where testing is not possible, it is necessary to agree on predictions of the sound power level due to load current including its harmonics based upon calculations. For detailed information see 4.2.5 and 7.6 as well as Annex A of IEC 60076-10-1:2016.

5 Sound level measurement specification

When sound level measurements are specified, the acoustic performance of a transformer shall be indicated by its A-weighted sound power level.

In exceptional cases, an average sound pressure level at a certain distance is allowed to be specified by the purchaser. The determination of that pressure level can either be obtained from a measurement of the spatially averaged sound pressure level at that distance or derived from the sound power determined at a different distance.

As a minimum, the sound power level at no-load excitation at rated voltage and frequency on an untapped winding shall be specified. For variable flux applications see 4.2.

If the transformer is equipped with a cooling device having pumps and/or fans then the cooling device's sound power level corresponding to the transformer's rated power shall also be specified. Duties other than that required for rated power can be specified by the purchaser.

Alternatively, the combined sum of the transformer no-load excitation and cooling device sound power level can be specified.

If the calculated sound power level due to load current according Equations (5) and (6) is considered significant by the purchaser, it is recommended to specify a measurement of the sound power level due to rated load current in order to report the transformer sound power level as in service.

NOTE 1 Distribution type transformers usually do not require consideration of sound power due to load current.

The purchaser may also specify a value for the sum of the sound power levels

- at no-load excitation,
- of the cooling device and
- due to load current,

all at the before mentioned rating.

Conditions other than those mentioned above, which might better reflect the likely service condition, can be agreed for sound measurements.

NOTE 2 It is in the purchaser interest to notify the manufacturer on any special service conditions, such as the presence of harmonics and/or d.c. bias in the network for the impact to the in service sound power level to be assessed.

In case of phase segregated transformers forming a three-phase bank the sound level specification shall be per phase segregated unit.

Methods used for the determination of sound power levels can be either sound pressure or sound intensity and are normally chosen by the purchaser. If not specified by the purchaser, the manufacturer shall choose the method and it shall be stated in the tender.

Sound measurements for distribution type transformers shall provide the total sound level as per definition 3.9 only, unless otherwise specified by the purchaser.

NOTE 3 This applies also to reactors with rated power lower than 1 MVA.

Sound measurements for all other transformers shall be executed with 1/3-octave band filtering, unless an alternative band width (octave-band or narrow-band) or a total sound level only is specified by the purchaser. For more details on narrow-band measurements see 5.4 and Annex A of IEC 60076-10-1:2016.

Sound measurements on all transformers and reactors shall be executed with an active part temperature close to ambient test bay conditions, unless the purchaser has specified sound measurements at close to service temperature conditions (usually performed at the end of a temperature rise test).

Unless otherwise specified by the purchaser, the choice between the use of the walk-around or the point-by-point procedure shall be at the discretion of the manufacturer.

NOTE 4 The difference in measured sound level due to the chosen method is negligible based on manifold comparisons but the walk-around procedure is less time consuming, especially in the case of large units.

The point-by-point procedure shall be applied when safety considerations dictate.

The point-by-point procedure is the logical choice in situations where there are a small number of measuring points. This normally applies to distribution type transformers.

6 Instrumentation, calibration and accuracy

The available frequency response of the measuring instrument shall range from below the rated power frequency to above the upper limit of the human ear capability of 20 kHz.

In case of transformers with a power frequency lower than 25 Hz and when the measuring device is limited in its lower frequency end then it is acceptable to have double the power frequency as the lower frequency end.

The upper limit for the actual measurement shall be chosen in accordance with the highest emitted significant frequency, usually below 10 kHz. The selected frequency range for background noise measurements and the test measurement shall be the same.

Sound pressure measurements shall be made using a type 1 sound level meter complying with IEC 61672-1 and IEC 61672-2 and calibrated in accordance with 5.2 of ISO 3746:2010.

The sound pressure method of measurements described in this standard is based on ISO 3746. Measurements made in conformity with this standard tend to result in standard deviations of reproducibility between determinations made in different laboratories which are less than or equal to 3 dB.

Sound intensity measurements shall be made using a class 1 sound intensity instrument complying with IEC 61043 and calibrated in accordance with 6.2 of ISO 9614-1:1993. The frequency range of the measuring equipment shall be adapted to the frequency spectrum of the test object, that is, an appropriate microphone spacer system shall be chosen in order to minimize systematic errors.

The sound intensity method of measurements described in this standard is based on ISO 9614-1 and ISO 9614-2. Measurements made in conformity with this standard tend to result in standard deviations of reproducibility between determinations made in different laboratories which are less than or equal to 3 dB.

The measuring equipment shall be calibrated in accordance with manufacturer's instructions immediately before and after the measurement sequence. If the calibration changes by more than 0,3 dB, the measurements shall be declared invalid and the test repeated.

All measurements shall be made using the energetic average over the measurement duration of the sound quantity (pressure or intensity). Statistically derived sound quantities such as percentiles shall not be applied.

The fast response indication of the meter shall be used to identify and avoid measurement errors due to transient background noise.

The sound level measurement is usually of manual operation but the errors introduced by varying distances will tend to average out. Their impact on the final measurement is of less significance than other acoustical factors. Nevertheless, all effort shall be made to keep the measurement distance as constant as possible.

NOTE Marking the contour on the floor or using a spacer between microphone and transformer can help to achieve the required measurement quality.

7 Principal radiating surface

7.1 General

The definition of the principal radiating surface depends on the type of cooling devices employed and their position relative to the transformer or its enclosure.

The height of the principal radiating surface is counted from the top of the test object to the floor of the test bay and includes the height of any supporting structure such as wheels, pallets, transportation cars. In case the supporting structure provides the acoustic properties of a reflecting plane and extends the string contour (as specified in following subclauses) of the test object by at least twice the measuring distance, then the supporting structure shall be considered as the floor.

7.2 Transformers with or without cooling device

The principal radiating surface is the surface obtained by the vertical projection of a string contour encircling the equipment. The projection runs from the top of the transformer tank cover (excluding protrusions such as bushings, turrets and other accessories situated above the tank cover) or the top of the cooling device, whatever is higher to the floor of the test bay. The principal radiating surface shall include cooling devices located < 3 m away from the transformer tank, tank stiffeners and such auxiliary equipment as cable boxes, tap-changer compartments, etc. It shall exclude any cooling devices located ≥ 3 m away from the transformer tank. Projections from protrusions such as bushings, oil pipework and conservators, valves, control cubicles and other secondary elements shall also be excluded as long as they do not interfere with the prescribed contour, see Figures 1, 2 and 3. Where protrusions interfere with the prescribed contour, then these parts are included within the principal radiating surface. In cases where the heights of the transformer and the cooling device deviate by more than a factor of two then the transformer and cooling plant sound levels shall be measured separately, even if the distance between both parts is less than 3 m.

7.3 Transformers in enclosures with cooling devices inside the enclosure

The principal radiating surface is the surface obtained by the vertical projection of a string contour encircling the equipment. The projection runs from the top of the enclosure (excluding protrusions such as bushings, turrets and other accessories situated above the enclosure) to the floor of the test bay.

7.4 Transformers in enclosures with cooling devices outside the enclosure

The principal radiating surface is the surface obtained by the vertical projection of a string contour encircling the equipment. The projection runs from the top of the transformer enclosure (excluding protrusions such as bushings, turrets and other accessories situated above the enclosure) or the top of the cooling device, whatever is higher to the floor of the test bay. The principal radiating surface shall include cooling devices located < 3 m away from the transformer enclosure, auxiliary equipment as cable boxes, tap-changer compartments, etc. It shall exclude cooling devices located ≥ 3 m away from the transformer enclosure. Projections from protrusions such as bushings, oil pipework and conservators, valves, control cubicles and other secondary elements shall also be excluded, see Figures 1, 2 and 3. In case of a transformer with sound panels, the sound panels are considered as the enclosure. In cases where the height of the transformer and the cooling device deviate by more than a factor of two then the transformer and cooling plant sound levels shall be measured separately, even if the distance between both parts is less than 3 m.

7.5 Cooling devices mounted on a separate structure where the distance between the two principal radiating surfaces is ≥ 3 m

The principal radiating surface is the surface obtained by the vertical projection of a string contour encircling the equipment but excluding protrusions such as oil conservators, framework, pipework, valves and other secondary elements. The vertical projection shall be from the top of the cooler structure to the floor of the test bay, see Figure 4. For cooling devices mounted several meters above floor level the prescribed contours shall be chosen in analogy to dry-type reactors, refer to Clause 8 and Figure 6 g).

NOTE In this case the prescribed contours will be at half of the height of the support structure and at the mid plane of the cooling device.

7.6 Dry-type transformers

In case of dry-type transformers without enclosure the principal radiating surface is the surface obtained by the vertical projection of a string contour encircling the dry-type transformer excluding protrusions such as framework, external wiring and connections and attached apparatus not affecting the sound radiation. The vertical projection shall be from the top of the transformer structure to the floor of the test bay, see Figure 5. The principal radiating surface shall include cooling devices attached to the transformer, if any.

In case of dry-type transformers with enclosure the principal radiating surface is the surface obtained by the vertical projection of a string contour encircling the equipment. The projection runs from the top of the transformer enclosure, excluding protrusions such as bushings, turrets and other accessories to the floor of the test bay. The principal radiating surface shall include cooling devices, auxiliary equipment as cable boxes, tap-changer compartments, etc., when attached to the transformer enclosure.

7.7 Dry-type air-core reactors

The principal radiating surface is the surface obtained by the vertical projection of a string contour encircling the equipment excluding protrusions such as external wiring and connections and attached apparatus such as arresters or surge capacitors not affecting the sound radiation. The projection runs from the top of the reactor to the floor of the test bay. The height of the principal radiating surface is therefore the sum of the height of the support structure to the floor of the test bay (h_S) and the height of the reactor coil (h_R). In case of a stacked reactor the height of the reactor (h_R) is the total height of the reactor stack, see Figure 6.

For single phase reactors or reactor stacks not equipped with sound shields, the string contour is the outer circumference of the reactor coil, see Figure 6 a).

For reactors equipped with sound shields, the string contour is the circumference of the sound shield.

For three-phase reactors mounted in a triangular arrangement the string contour envelops all three reactor phase-coils and is shown in Figure 6 b).

For three-phase reactors mounted side-by-side the string contour envelops all three of the reactor phase-coils and is shown in Figure 6 c).

8 Prescribed contour

For distribution type transformers, where factories have small test facilities or when anechoic chambers are used for sound measurements, the prescribed contour shall be spaced 0,3 m away from the principal radiating surface.

For dry-type transformers without enclosures, the prescribed contour shall be spaced 1 m away from the principal radiating surface for safety reasons.

For all other transformers, the prescribed contour shall be spaced 1 m away from the principal radiating surface unless the following conditions apply, where the distance may necessarily be reduced to 0,3 m:

- limited space in the test bay;
- low signal-to-noise ratio in case of low-noise transformers and/or high background noise.

NOTE 1 A low signal-to-noise ratio is indicated if the validation criteria for the selected test method cannot be met, see 11.2.4 and 11.3.4.

For measurements made with forced air cooling devices in service, the prescribed contour shall be spaced 2 m away from the principal radiating surface to minimise the effects of air turbulences. For dry-type units with and without enclosure and with forced air cooling devices in service, the prescribed contour shall be spaced 1 m away from the principal radiating surface as turbulences in such applications are normally limited.

NOTE 2 The length of the prescribed contour can either be measured in the test bay or calculated from a drawing or CAD model.

For a particular test set-up the one selected measurement distance applies around the entire test object. Different measurement distances can apply for different test set-ups as for example a change from 1 m to 2 m, when fans are running.

NOTE 3 Background information for the selection of the measurement distances is given in 5.5 of IEC 60076-10-1:2016.

For transformers and/or cooling devices with a height of < 2,5 m, the prescribed contour shall be on a horizontal plane at half the height. For transformers and/or cooling devices with a height ≥ 2,5 m, two prescribed contours shall be used which are on horizontal planes at one-third and two-thirds of the height. For safety reasons, alternative heights can be selected.

For dry-type air-core reactors the prescribed contour shall be spaced 2 m away from the principal radiating surface, however for field measurements it may be necessary for safety reasons to increase the spacing.

Depending on the height of the support structure and the height of the reactor coil/stack one or two prescribed contours on horizontal planes shall be used:

- $h_S \leq 2$ m and $h_R \leq 4$ m: 1 prescribed contour (see Figure 6 d));
- $h_S \leq 2$ m and $h_R > 4$ m: 2 prescribed contours (see Figure 6 e) and Figure 6 f));

- $h_S > 2$ m and any h_R: 2 prescribed contours (see Figure 6 g));

where

h_S is the height of the support structure;

h_R is the height of the coil / stack.

9 Microphone positions

For the walk-around procedure, the microphone shall be moved with a constant speed of maximum 1 m/s on the prescribed contour(s) around the test object. At the given walking speed, the sampling rate of modern integrating sound level meters is always sufficient for accurate spatial averaging up to a resolution of 1/3-octave. The spatially averaged sound level over the measurement duration shall be recorded together with the active measurement duration in the test report.

NOTE The “START – STOP” and “PAUSE” functions of such sound level meters can be used to simplify the measuring procedure, i.e. to negotiate obstacles and/or to change between prescribed contours.

For the point-by-point procedure, the microphone positions shall be on the prescribed contour(s), equally spaced and not more than 1 m apart (see dimension D in Figures 1 to 5). There shall be a minimum of eight microphone positions along each contour. The measuring duration shall be a minimum of three seconds and be practically the same duration at each position.

It can be necessary to modify some measuring positions for certain test objects for safety reasons, for example, in the case of transformers with horizontal high voltage bushings where part of the prescribed contour(s) may be confined to the safe zone.

10 Calculation of the measurement surface area

10.1 Measurement surface area for measuring distances up to 30 m

The area S of the measurement surface, expressed in square metres, is given by Equation (8):

$$S = (h + x)\, l_m \qquad (8)$$

where

h is the height of the principal radiating surface in meters as per Clause 7;

l_m is the length in metres of the prescribed contour;

x is the measurement distance in meters from the principal radiating surface to the prescribed contour.

NOTE 1 Equation (8) applies for the measuring distances of 0,3 m, 1 m, 2 m but also any other measuring distance up to 30 m.

NOTE 2 Equation (8) is also applicable for the calculation of the sound pressure level from the sound power level.

10.2 Measurement surface area for measuring distances larger than 30 m

The area S of the measurement surface (a hemisphere), expressed in square metres, is given by Equation (9):

$$S = 2 \times \pi \times R^2 \qquad (9)$$

where

R is the distance in meters from the geometrical centre of the transformer / cooling device to the considered location in the far-field.

NOTE Equation (9) is also applicable for the calculation of the sound pressure level from the sound power level. For further information on far-field calculations, see Clause 14.

11 Sound measurement

11.1 Test conditions

11.1.1 Placement of test object

The following conditions shall be met in order to satisfy the assumptions for the enveloping method according to ISO 3746 for sound pressure measurements and ISO 9614-2:1996 for sound intensity measurements.

An environment having an approximately free field over a reflecting plane shall be used. The reflecting plane shall preferably have an acoustic absorption coefficient of less than 0,1 over the frequency range of interest, see Clause 6. This requirement is usually fulfilled when indoor measurements are made over concrete, resin, steel or hard tile flooring or when outdoor measurements are made over concrete, sealed asphalt, sand or stone surfaces. The reflecting plane shall be larger than the area within the prescribed contour.

Care shall be taken to ensure that the reflecting plane (supporting surface) does not radiate an appreciable sound power due to vibration.

It is acceptable to close gaps between test room floor and transformer tank bottom with sound absorbing material which appear as a result of the test set up only and which do not appear in service. However, any other sound absorbent materials placed on the floor within the area of the prescribed contour shall be removed during test.

The measurement surface shall lie within a sound field essentially undisturbed by reflections from nearby objects and the environment boundaries. Reflecting objects shall therefore be removed as far as possible from the test object. Placing the test object not in parallel to reflecting walls and as far away as possible from those will help to minimise reflections. For more information see also 6.3 of IEC 60076-10-1:2016. The use of sound absorbing panels outside the area of the prescribed contour will also improve the test environment.

The enveloping method is not applicable for measurements inside reverberant transformer cells or enclosures.

11.1.2 Test energisation options

The following options for transformer energisation are available and shall be applied as specified and agreed upon with the equipment under test at ambient temperature, see Clause 4.

a) transformer at no-load excitation without cooling device(s);
b) transformer at no-load excitation with cooling device(s);
c) transformer at load current in short-circuit condition without cooling device(s);
d) transformer at load current in short-circuit condition with cooling device(s);
e) cooling device(s) only.

If the measurement of a specific combination is not specified to be actually measured then it is acceptable to derive the sound power level of this specific combination by logarithmic addition or subtraction of the individual measurements.

NOTE 1 It is established practice, to measure the individual sound level components during type test however the subsequent routine tests on identical units are generally performed without coolers mounted. Option a) and c) are then measured (if specified) and the cooler sound level from the type test is added.

NOTE 2 Configuration c) can be applied only if no significant local temperature rise is expected in any section of the winding arrangement.

If a sound level test is specified to be performed at a temperature close to service temperature then the top-liquid temperature is to be measured and noted in the test report.

NOTE 3 A minimum of time spent for a sound level measurement avoids changes in the sound level caused by changes in transformer temperature.

NOTE 4 The DC bias impact on no-load sound level measurements during factory testing can be practically eliminated by an over-excitation run for some minutes, see also 4.2.

11.1.3 Test application details

The test method (pressure method, intensity method), test procedure (walk-around procedure, point-by-point procedure), filtering bandwidth and transformer temperature (ambient or close to service) shall be as specified, see Clause 5. If nothing is specified by the purchaser then the measurement methods and procedures will be selected by the manufacturer from the available options within this standard in order to measure the required sound levels.

11.1.4 Prevailing ambient conditions

For the integrity of both methods described below a steady-state background noise level throughout the sound level measurement shall be maintained.

NOTE If the background noise is frequently disturbed then it can be preferable to use the point-by-point procedure.

Outdoor measurements shall not be made under extreme meteorological conditions, for example, in the presence of temperature gradients, strong wind speeds, any type of precipitation, snow accumulations and at high humidity for measurements at distances larger than 10 m.

11.2 Sound pressure method

11.2.1 General

Sound pressure measurements around the test object are affected by the test environment and the following corrections shall be made, as applicable:

- correction for steady-state background noise;
- correction for sound reflections by factor K.

NOTE Sound field effects close to the test object (near field effects) can impact sound pressure measurements at a measuring distance of 0,3 m. They tend to increase the measured sound pressure level in the range of 0,5 dB to 1,5 dB.

11.2.2 Test procedure

The intention of this test is to report the total spatially averaged A-weighted sound pressure level for each energisation option accompanied with a single spatially averaged frequency spectrum (where applicable).

The same test procedure (either walk-around procedure or point-by-point procedure) applies for both background noise measurements and test measurements.

The microphone(s) positions as described in Clause 9 apply for both background noise measurements and test measurements.

For the point-by-point procedure, when the number of measuring positions exceeds 10, it is permissible to measure the background noise level at only 10 positions equally distributed around the test object.

A total spatially averaged background noise level (see definition 3.17) and the corresponding frequency spectrum shall be recorded immediately before and after each test measurement sequence. Where the point-by-point procedure is applied, it is possible to determine the frequency spectrum from the average of the spectra measured at all individual microphone positions or by an additional walk-around measurement. If the latter is applied this shall be clearly mentioned in the test report.

If the background noise level is at least 10 dB below that of the test object then the background noise can be measured at only one location on the prescribed contour and a background noise correction is not necessary.

A total spatially averaged A-weighted sound pressure level together with the corresponding frequency spectrum shall be recorded for either the walk-around procedure or the point-by-point procedure as appropriate. For the point-by-point procedure the purchaser can additionally request individual total A-weighted sound pressure levels to be recorded for each microphone position. Where the point-by-point procedure is specified, it is possible to determine the frequency spectrum by taking the average of the spectra taken at all individual microphone positions or by an additional walk-around measurement. If the latter is applied this shall be clearly mentioned in the test report.

11.2.3 Calculation of the spatially averaged sound pressure level

For the walk-around procedure the instrument will automatically provide the spatially averaged measurement data. In case of the point-by-point procedure the spatially averaged measurement data may also be derived automatically by the instrument via post-processing or it has to be calculated as described below. When required to report point-by-point measurements for each microphone position it may be necessary to derive the total spatially averaged sound pressure level by calculation. The total spatially averaged A-weighted sound pressure level for the test measurement, $\overline{L_{\text{pA0}}}$, shall then be calculated from the total A-weighted sound pressure levels, L_{pAi}, measured at the individual microphone positions using Equation (10):

$$\overline{L_{\text{pA0}}} = 10 \times \lg\left(\frac{1}{N}\sum_{\text{i}=1}^{N} 10^{0,1 L_{\text{pAi}}}\right) \tag{10}$$

where

N is the number of microphone positions;

L_{pAi} is the measured total A-weighted sound pressure level of the test measurement at the i^{th} microphone position.

The total spatially averaged A-weighted background noise level, $\overline{L_{\text{bgA}}}$, shall be calculated before and after the test sequence using Equation (11):

$$\overline{L_{\text{bgA}}} = 10 \times \lg\left(\frac{1}{M}\sum_{\text{i}=1}^{M} 10^{0,1 L_{\text{bgAi}}}\right) \tag{11}$$

where

M is the number of microphone positions;

$L_{\mathrm{bgA}i}$ is the measured total A-weighted background noise level at the i^{th} microphone position.

The same calculation procedure applies for each individual band ν of the frequency spectrum resulting in spatially averaged A-weighted sound pressure levels $\overline{L_{\mathrm{pA0}}^{\nu}}$ and spatially averaged background noise levels $\overline{L_{\mathrm{bgA}}^{\nu}}$.

11.2.4 Validation of test measurements with respect to background noise

For practical purposes the validation process described below is based on the total spatially averaged A-weighted sound pressure level $\overline{L_{\mathrm{pA0}}}$ and the total background noise level $\overline{L_{\mathrm{bgA}}}$. Examination of individual bands of the frequency spectrum is not required.

When initial and final background noise levels $\overline{L_{\mathrm{bgA}}}$ differ by more than 3 dB and when the higher value is less than 8 dB below the A-weighted sound pressure level of the test measurement $\overline{L_{\mathrm{pA0}}}$, the test measurement shall be declared invalid and the test repeated. However, in cases where the test measurement meets the guarantee, correction for background noise is not required. In this case the test is declared a pass.

If the greater of the two background noise levels $\overline{L_{\mathrm{bgA}}}$ is less than 3 dB below the A-weighted sound pressure level of the test measurement $\overline{L_{\mathrm{pA0}}}$, the test measurement shall be declared invalid and the test repeated. However, in cases where the test measurement meets the guarantee, correction for background noise is not required. In this case the test is declared a pass.

Whilst this standard permits small differences between background noise and test measurement sound levels, every effort should be made to obtain a difference of about 6 dB. When the difference becomes less than 3 dB, the use of alternative measurement methods may be considered (see 11.3 and Annex A).

The above requirements are summarized in Table 1.

Table 1 – Test acceptance criteria

$\overline{L_{\mathrm{pA0}}}$ – the higher $\overline{L_{\mathrm{bgA}}}$	Initial $\overline{L_{\mathrm{bgA}}}$ – final $\overline{L_{\mathrm{bgA}}}$	Decision
≥ 8 dB	–	Accept test
< 8 dB	< 3 dB	Accept test
< 8 dB	> 3 dB	Repeat test [a]
< 3 dB	–	Repeat test [a]

[a] Unless $\overline{L_{\mathrm{pA0}}}$ meets the guarantee. Correction for background noise is not required in this case and the test is declared a pass.

11.2.5 Calculation of environmental correction *K*

11.2.5.1 General

The environmental correction K, expressed in dB, accounts for the influence of undesired sound reflections from room boundaries and/or reflecting objects within the test area. The magnitude of K depends principally on the ratio of the sound absorption area of the test room, A, to the area of the measurement surface, S. The magnitude of K is not strongly influenced by the location of the test object in the test room and K does not correct for measurements influenced by standing waves.

K shall be derived from Equation (12) or Figure 7 by entering the appropriate value of A/S.

$$K = 10 \times \lg\left(1 + \frac{4}{A/S}\right) \quad (12)$$

The environmental correction factor K shall preferably be determined by measurement techniques. However, for the purpose of this standard estimation for K is allowed by use of absorption coefficients.

For a test room to be satisfactory, the ratio A/S shall be ≥ 1 with a corresponding value for the environmental correction factor $K \leq 7$ dB. However, if the ratio A/S is ≤ 2,5 with a corresponding value for the environmental correction factor $K \geq 4{,}1$ dB, then the determination of K shall be based on acoustical measurements.

Where conditions are close to free-field, i.e. essentially undisturbed by reflections from nearby objects and the environment boundaries, as sometimes achieved for outdoor measurements, then the value for K would tend to zero and no environmental correction is necessary.

11.2.5.2 Determination of K based on measurement of the reverberation time

The reverberation time of the test room is determined by exciting the test room with broadband sound or impulsive sound and measuring the decaying response as A-weighted broadband or more precisely for individual bands of the frequency spectrum, as per ISO 3382-2:2008.

The value of A is given in square metres by Sabine's Equation (13):

$$A = 0{,}16\ (V/T) \quad (13)$$

where

V is the volume of the test room in cubic metres;

T is the reverberation time of the test room in seconds.

Equation (13) applies for the broadband A weighted response and also for individual bands of the frequency spectrum when K is determined individually for the frequency bands.

Whilst the application of K for the individual frequency bands will provide a more accurate correction, for practical purposes it is possible to apply only one K factor for the whole spectrum.

Ideally, the determination of K is performed before each measurement with test lab equipment and test objects in place. Because this is often not practical the determination of K can also be done once as reference with the test lab empty of all unnecessary equipment.

NOTE 1 K determined with the test lab empty of all unnecessary equipment results in the lowest possible value.

NOTE 2 The determination of the sound absorption area A with all unnecessary equipment removed from the test lab can preferably be provided by an independent agency and the certificate be used to demonstrate the determination of K to the purchaser on request.

11.2.5.3 Determination of K based on absorption coefficients

The value of the sound absorption area A in square metres is given by Equation (14):

$$A = \sum_{i} \alpha_i \times S_{Vi} \tag{14}$$

where

α_i is the acoustic absorption coefficient for a partial surface (see Table 2);

S_{Vi} is the area of the partial surface of the test room (walls, ceiling and floor) characterised by α_i in square metres.

Table 2 – Approximate values of the average acoustic absorption coefficient

Description of surface	Average acoustic absorption coefficient, α
Hard floor	0,1
Walls and ceilings within a irregularly shaped machinery room or production facility, test bay walls and ceiling without acoustic damping material	0,2
Walls and ceilings with acoustic damping material of up to 20 cm thickness	0,3
Walls and ceilings with acoustic damping material of more than 20 cm thickness	0,5
Open gates with large room behind	0,5

The entire surface of the volume of the test room shall match the sum of the partial surfaces S_{Vi} in Equation (14), including walls, ceiling, floor and open gates.

The above mentioned calculation for the sound absorption area A according Equation (14) shall be included in the test report.

The determination of K with this method applies as correction for both the total A-weighted sound pressure level and for individual bands of the frequency spectrum.

11.2.5.4 Alternative method for the estimation of *K*

Alternatively, K can be determined by measuring, in the test facility, the apparent sound power level of a reference sound source. The reference sound source will have been previously calibrated in a free field over a reflecting plane. It then can be written

$$K = L_{Wm} - L_{Wr} \tag{15}$$

where

L_{Wm} is the sound power level of the reference sound source, determined according to Clauses 7 and 8 of ISO 3746:2010 not accounting for reflected sound;

L_{Wr} is the measured apparent sound power level of the reference sound source measured in the test facility accounting for reflected sound ($L_{Wr} > L_{Wm}$).

The determination of K with this method applies as correction for both the total A-weighted sound pressure level and for individual bands of the frequency spectrum, as long as the sound power of the reference source was estimated using frequency selective techniques.

NOTE This method is often utilised at small test facilities.

11.2.6 Final correction for steady-state background noise and test environment

The corrected total spatially averaged A-weighted sound pressure level, $\overline{L_{pA}}$, used for the sound power calculation (see Clause 12), shall be derived from Equation (16):

$$\overline{L_{\text{pA}}} = 10 \times \lg\left(10^{0,1\overline{L_{\text{pA0}}}} - 10^{0,1\overline{L_{\text{bgA}}}}\right) - K \tag{16}$$

where $\overline{L_{\text{bgA}}}$ is the lower of the two total spatially average A-weighted background noise levels.

The same calculation procedure applies for individual bands ν of the frequency spectrum resulting in corrected spatially averaged A-weighted sound pressure levels $\overline{L_{\text{pA}}^{\nu}}$, used for the sound power calculation of the individual frequency bands. Background noise levels in individual bands $\overline{L_{\text{bgA}}^{\nu}}$ all refer to the lower of the two total spatially averaged A-weighted background noise levels $\overline{L_{\text{bgA}}}$.

If Equation (16) is applied for individual frequency bands ν then the total sound pressure level is the logarithmic sum of the corrected sound pressure level of the individual frequency bands.

In circumstances when a background noise level in a specific band $\overline{L_{\text{bgA}}^{\nu}}$ is greater than the test measurement sound pressure level $\overline{L_{\text{pA0}}^{\nu}}$ in the same band, then the corresponding $\overline{L_{\text{pA}}^{\nu}}$ shall be taken as zero.

11.3 Sound intensity method

11.3.1 General

The sound intensity method is, within certain limits, insensitive to steady-state background noise and reflections. Therefore corrections need not be applied. For more information see also IEC 60076-10-1:2016.

It is inherent to the sound intensity method that the measurement surface and therefore the measurement path shall completely encircle the test object. This is because sound intensity is a vector quantity.

Where tank walls are partially covered by panels, the intensity method is not applicable because the intensity level measured at the microphone positions will not be representative to the complete transformer surface. For more information see 6.5 of IEC 60076-10-1:2016.

11.3.2 Test procedure

Both the normal sound intensity level and the sound pressure level shall be recorded for each measurement.

The microphone spacer within the intensity probe shall be selected to cover the necessary sound spectrum to be measured, otherwise the lower or upper frequencies will not correctly be taken into account and errors will be introduced. Different microphone spacers may need to be used for the various energisation options, see 11.1.2.

The sound intensity probe (microphone pair) positions as described in Clause 9 apply for the measurements. As the probe has directivity and polarity, it is essential to maintain the axis of the probe normal and with its correct direction to the measurement surface.

The intention of this test is to report the total spatially averaged A-weighted normal sound intensity and sound pressure level for each energisation option accompanied with a single spatially averaged frequency spectrum (where applicable).

The specified test procedure shall be applied for the measurement (walk-around procedure or point-by-point procedure).

A total spatially averaged A-weighted normal sound intensity and sound pressure level together with the corresponding frequency spectrum shall be recorded for either the walk-around procedure or the point-by-point procedure as appropriate. For the point-by-point procedure the purchaser can additionally request individual total A-weighted normal sound intensity and sound pressure levels to be recorded for each microphone position. Where the point-by-point procedure is specified, it is possible to determine the frequency spectrum by taking the average of the spectra taken at all individual microphone positions or by an additional walk-around measurement. If the latter is applied this shall be clearly mentioned in the test report.

11.3.3 Calculation of average normal sound intensity and sound pressure level

For the walk-around procedure the instrument will automatically provide the spatially averaged measurement data (normal intensity level $\overline{L_{\text{IA0}}}$ and its direction flag $\overline{F_{\text{Dir}}}$ and the sound pressure level $\overline{L_{\text{pA0}}}$). In case of the point-by-point procedure the spatially averaged measurement data may also be derived automatically by the instrument, via post-processing or it has to be calculated as described below. When required to report point-by-point measurements for each microphone position it may be necessary to derive the total spatially averaged normal sound intensity and sound pressure level by calculation. The total spatially averaged A-weighted normal sound intensity level $\overline{L_{\text{IA0}}}$ shall be calculated from the total A-weighted normal sound intensity levels L_{IAi} measured at the individual microphone positions according to Equations (17) and (18):

$$\overline{L_{\text{IA0}}} = 10 \times lg \left| \frac{1}{N} \sum_{i=1}^{N} F_{\text{Diri}} \times 10^{0,1 L_{\text{IAi}}} \right| \tag{17}$$

$$\overline{F_{\text{Dir}}} = Sign \left(\frac{1}{N} \sum_{i=1}^{N} F_{\text{Diri}} \times 10^{0,1 L_{\text{IAi}}} \right) \tag{18}$$

where

F_{Diri} is the direction flag according definition 3.6 at the i^{th} microphone position;

$\overline{F_{\text{Dir}}}$ is the direction flag indicating the net energy flow;

N the number of microphone positions.

The total spatially averaged A-weighted sound pressure level $\overline{L_{\text{pA0}}}$ shall be calculated from the sound pressure levels L_{pAi}, measured at the individual microphone positions using Equation (10).

The same calculation procedure applies for individual bands ν of the frequency spectrum resulting in spatially averaged A-weighted normal sound intensity levels $\overline{L^{\nu}_{\text{IA0}}}$ and sound pressure levels $\overline{L^{\nu}_{\text{pA0}}}$.

11.3.4 Measurement validation

Where there is a noticeable change in background noise during a measurement the measurement shall be rejected.

For practical purposes the validation process described below is based on the measured total spatially averaged A-weighted normal sound intensity and sound pressure levels, $\overline{L_{\text{IA0}}}$ and $\overline{L_{\text{pA0}}}$ respectively. Examination of individual bands of the frequency spectrum is not required.

The criterion for judging the acceptability of the test environment and the acceptability of the steady-state background noise is the P-I index as per definition 3.19 and is given by Equation (19):

$$\Delta L = \overline{L_{\text{pA0}}} - \overline{L_{\text{IA0}}} \tag{19}$$

If $\Delta L > 8$ dB, the measurement shall be declared invalid.

If 4 dB $< \Delta L \leq$ 8 dB, the measurement shall be accepted with a correction applied, see 11.3.5.

If $\Delta L \leq 4$ dB, the measurement is valid without correction.

NOTE If $\Delta L > 8$ dB, the re-arrangement of the test setup, an alternative measuring distance or an alternative measurement method (sound pressure method, narrow-band measurement, time-synchronous measurement) can be considered. See also Annex A.

If the direction flag for the total spatially averaged normal sound intensity level $\overline{F_{\text{Dir}}}$ becomes -1, this indicates either the overall energy flow being towards the test object or an erroneous measurement and the test is declared invalid.

Where the direction flag for the spatially averaged normal sound intensity level of an individual band of the frequency spectrum becomes -1, this indicates the net energy flow in that frequency band being towards the test object. This occurs when the radiated sound from the test object is negligible and this is acceptable.

11.3.5 Final correction based on P-I index and direction flag

The corrected total spatially averaged A-weighted normal sound intensity level $\overline{L_{\text{IA}}}$ used for the sound power calculation (see Clause 12), shall be derived from $\overline{L_{\text{IA0}}}$ and $\overline{L_{\text{pA0}}}$ as follows:

If $\Delta L \leq 4$ dB: $\overline{L_{\text{IA}}} = \overline{L_{\text{IA0}}}$ (i.e. no correction required); (20)

If 4 dB $< \Delta L \leq$ 8 dB: $\overline{L_{\text{IA}}} = \overline{L_{\text{pA0}}} - 4\ \text{dB}$. (21)

The same correction as for the total spatially averaged A-weighted normal sound intensity level $\overline{L_{\text{IA}}}$ of a measurement shall be applied to all individual bands ν.

NOTE The PI-index of individual bands frequently will exceed the permissible value of 8 dB for the overall PI-index. This is consistent with the measuring principle and usually indicates a small sound power involved.

Where the direction flag for an individual band ν becomes -1, the corrected sound intensity level $\overline{L_{IA}^{\nu}}$ shall be taken as zero for this band.

12 Determination of sound power level by calculation

The total A-weighted sound power level of the test object, L_{WA}, shall be calculated from either the corrected total spatially averaged A-weighted sound pressure level, $\overline{L_{pA}}$, or the corrected total spatially averaged A-weighted normal sound intensity level, $\overline{L_{IA}}$, according to Equation (22) or (23), respectively:

$$L_{WA} = \overline{L_{pA}} + 10 \times \lg \frac{S}{S_0} \tag{22}$$

$$L_{WA} = \overline{L_{IA}} + 10 \times \lg \frac{S}{S_0} \tag{23}$$

where S is derived from Equation (8) and S_0 is equal to the reference area (1 m^2).

The same calculation procedure applies for individual bands ν of the frequency spectrum resulting in A-weighted sound power levels L_{WA}^{ν} of the individual frequency bands. Sound power levels of frequency bands with $\overline{L_{pA}^{\nu}}$ or $\overline{L_{IA}^{\nu}}$ taken as zero are irrelevant and consequently set to zero.

13 Logarithmic addition and subtraction of individual sound levels

There are situations where it is necessary to add or subtract sound levels. Such situations are

- combination of sound levels for different loading conditions;
- combination of sound levels for individual bands of the frequency spectrum for different loading conditions;
- summation of individual band sound levels to a total sound level;
- summation of intensity levels when it was necessary to use different spacers to cover the entire frequency range of a specific measurement.

The equations given in this clause apply equally to the sound level quantities of pressure, intensity and power. For sound pressure and for sound intensity it is necessary that individual components refer to the same measuring point or prescribed contour. For sound intensity it is also necessary that the orientation of the measuring probe is identical for the individual measurements.

Equation (24) applies for the addition of sound levels of different sources or bands without a direction flag:

$$L_{sum} = 10 \times \lg \left(10^{0,1L_1} + 10^{0,1L_2} + \ldots + 10^{0,1L_n} \right) \tag{24}$$

where

L_1 is the 1st sound level;

L_2 is the 2nd sound level;

L_n is the nth sound level.

Equation (24) also applies for subtraction operations of sound levels at different loading conditions.

Equation (24) is used for all sound levels determined by the pressure method including frequency bands and for total sound levels determined by the intensity method.

Equations (25) and (26) apply for the addition of sound levels of different sources or bands with a direction flag as for individual bands of sound levels determined by the intensity method:

$$L_{\text{sum}} = 10 \times \lg \left| F_{\text{Dir1}} \times 10^{0,1L_1} + F_{\text{Dir2}} \times 10^{0,1L_2} + \ldots + F_{\text{Dir n}} \times 10^{0,1L_\text{n}} \right| \quad (25)$$

$$F_{\text{Dir sum}} = Sign \left(F_{\text{Dir1}} \times 10^{0,1L_1} + F_{\text{Dir2}} \times 10^{0,1L_2} + \ldots + F_{\text{Dir n}} \times 10^{0,1L_\text{n}} \right) \quad (26)$$

where

L_1, L_2, L_n are the 1st, 2nd and nth sound levels;

L_{sum} is the sound level of the summation;

F_{Dir1}, F_{Dir2}, F_{Dirn} are the 1st, 2nd and nth direction flags of the sound levels L_1, L_2, L_n;

$F_{\text{Dir sum}}$ is the direction flag of L_{sum}.

Equations (25) and (26) also apply for subtraction operations of sound levels at different loading conditions.

14 Far-field calculations for distances larger than 30 m

When the purchaser specification requires the sound pressure of the equipment at a certain distance to be quoted the following applies.

As an approximate calculation, assuming a point source and free-field conditions over a reflecting plane, the sound pressure level, L_{pR}, at a distance R in metres from the geometrical centre of the source is given by Equation (27):

$$L_{\text{pR}} = L_\text{W} - 10 \times \lg \frac{S_\text{h}}{S_0} \quad (27)$$

where

$S_\text{h} = 2 \times \pi \times R^2$ is the area of the surface of a hemisphere of radius R, and R is greater than 30 m;

S_0 is the reference area (1 m^2);

L_W is the sound power level.

For a more accurate value, factors such as directional characteristics, reflections, screening and atmospheric absorption need to be considered. Sound propagation simulations using numerical techniques may be required. These are normally not available to the transformer manufacturer.

15 Presentation of results

The report shall include all the following information:

a) name of manufacturer and place of manufacture and test;
b) date of tests;
c) description of the test object giving its serial number, rated power, rated voltage, frequency, tap-position for sound measurements due to load;
d) guaranteed sound level and the loading and measurement conditions against which this guaranteed level is demonstrated;
e) top-liquid temperature in case where sound level measurements are performed at temperature close to service temperature;
f) reference to this measurement standard IEC 60076-10;
g) sound power level determination method and procedure used;
h) identification of sound measuring equipment and calibration verification including serial numbers of the instruments, microphone(s) and calibration source;
i) dimensioned sketch of the test object and the measuring positions;
j) test conditions for each test configuration including voltage, current, tap position, cooling devices used and noise mitigation features employed during test;
k) length of the measurement distance, the prescribed contour(s), the height of the test object and the calculated measurement surface area;
l) name of the test engineer and witnesses where necessary;
m) signature of the person responsible for testing.

When the sound pressure method is used, the following information shall be included:

n) point-by-point procedure: the total A-weighted sound pressure level of the background noise at each background noise measuring position and, where applicable, a spatially averaged frequency spectrum immediately before and immediately after the measurement sequence;
o) walk-around procedure: the total spatially averaged A-weighted sound pressure level of the background noise and, where applicable, a spatially averaged frequency spectrum immediately before and immediately after the measurement sequence;
p) point-by-point procedure: the total A-weighted sound pressure level for each measuring position, the total spatially averaged A-weighted sound pressure level $\overline{L_{\text{pA0}}}$ and, where applicable, a spatially averaged frequency spectrum for each of the performed loading conditions;
q) walk-around procedure: the total spatially averaged A-weighted sound pressure level $\overline{L_{\text{pA0}}}$ and, where applicable, a spatially averaged frequency spectrum for each of the performed loading conditions;
r) the value of the environmental correction K, either broadband or frequency band specific;
s) when the environmental correction K is derived by calculation from absorption coefficients, the calculation of the sound absorption area A; when the environmental correction K is based on measurements of the sound absorption area A, the reference to the certificate of the independent agency which made the measurements; when the environmental correction K is derived by utilisation of a reference sound source, the reference to the certificate of the sound source calibration;

t) corrected total spatially averaged A-weighted sound pressure level, $\overline{L_{pA}}$ and, where applicable, a corrected spatially averaged frequency spectrum for each of the performed loading conditions;

u) total A-weighted sound power level, L_{WA} and, where applicable, a frequency spectrum L_{WA}^{ν}, for each of the performed loading conditions;

v) summation of the derived sound power levels for the loading combinations to be guaranteed, only at this final stage to be rounded to the nearest integer.

When the sound intensity method is used, the following information shall be included:

w) point-by-point procedure: the total A-weighted sound pressure and intensity level with its direction flag F_{Dir} for each measuring position, the total spatially averaged A-weighted sound pressure and intensity level $\overline{L_{pA0}}$ and $\overline{L_{IA0}}$ with its direction flag $\overline{F_{Dir}}$ and, where applicable, a spatially averaged frequency spectra of the sound pressure and intensity level with its flags for each of the performed loading conditions;

x) walk-around procedure: the total spatially averaged A-weighted sound pressure and intensity level $\overline{L_{pA0}}$ and $\overline{L_{IA0}}$ with its direction flag $\overline{F_{Dir}}$ and, where applicable, the spatially averaged frequency spectra of the sound pressure and intensity level with its flags for each of the performed loading conditions;

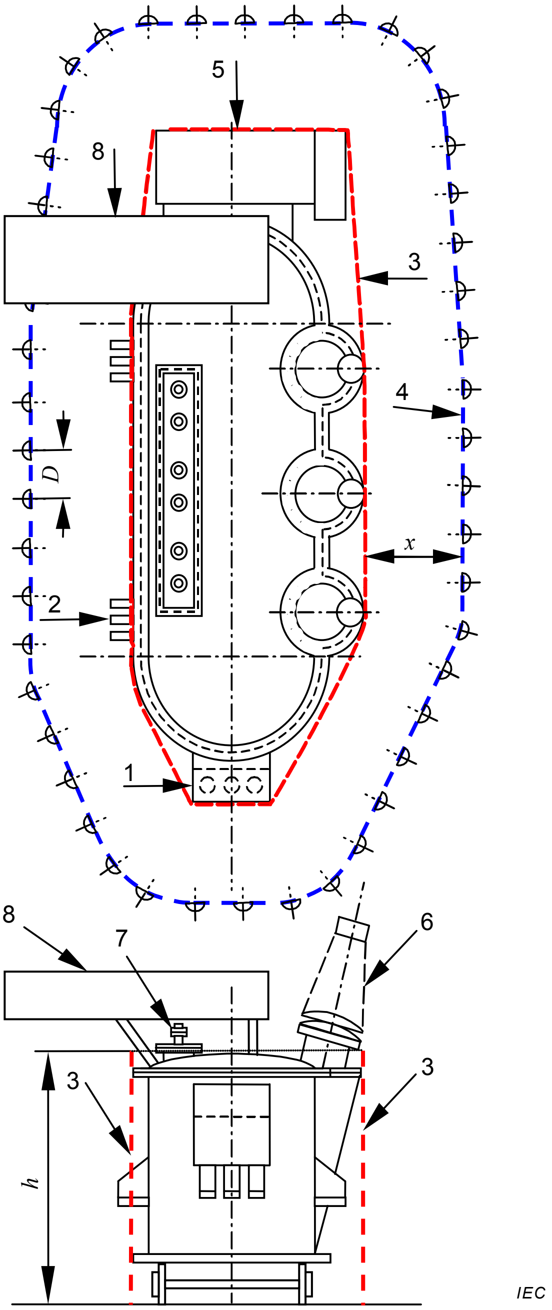
y) value of ΔL for each of the performed loading conditions;

z) corrected total spatially averaged A-weighted normal sound intensity level $\overline{L_{IA}}$ for each of the performed loading conditions;

a1) total A-weighted sound power level, L_{WA} and, where applicable, a frequency spectrum L_{WA}^{ν}, with its direction flags for each of the performed loading conditions;

b1) summation of the derived sound power levels for the loading combinations to be guaranteed, only at this final stage to be rounded to the nearest integer.

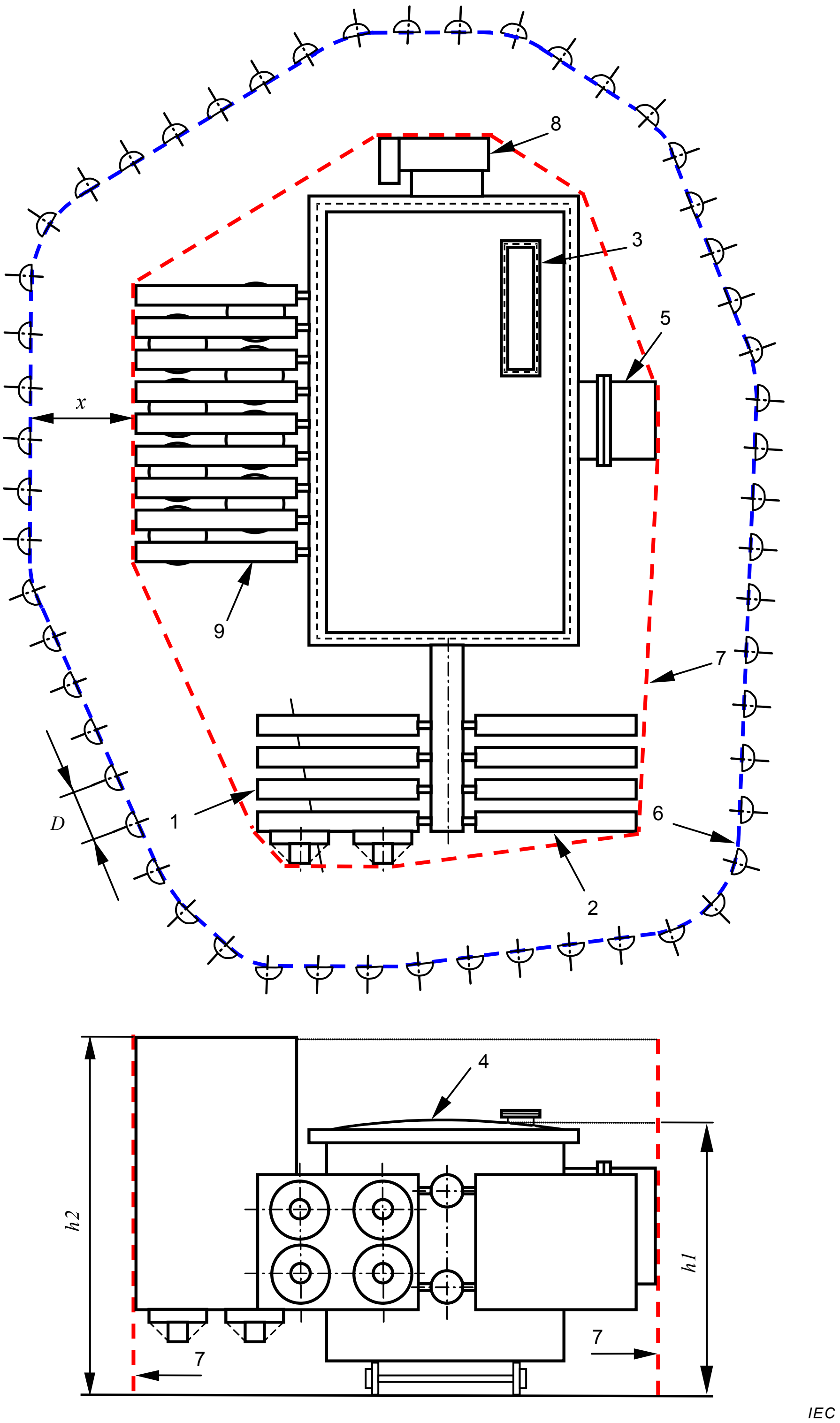
NOTE A typical form for the presentation of results is given in Annex B.



Key

1 Tertiary bushings
2 Stiffeners and jacking lug
3 Principal radiating surface
4 Prescribed contour
5 On-load tap-changer
6 HV bushings
7 LV bushings
8 Conservator
D Microphone spacing (if applicable)
h Height of the principal radiating surface
x Measurement distance

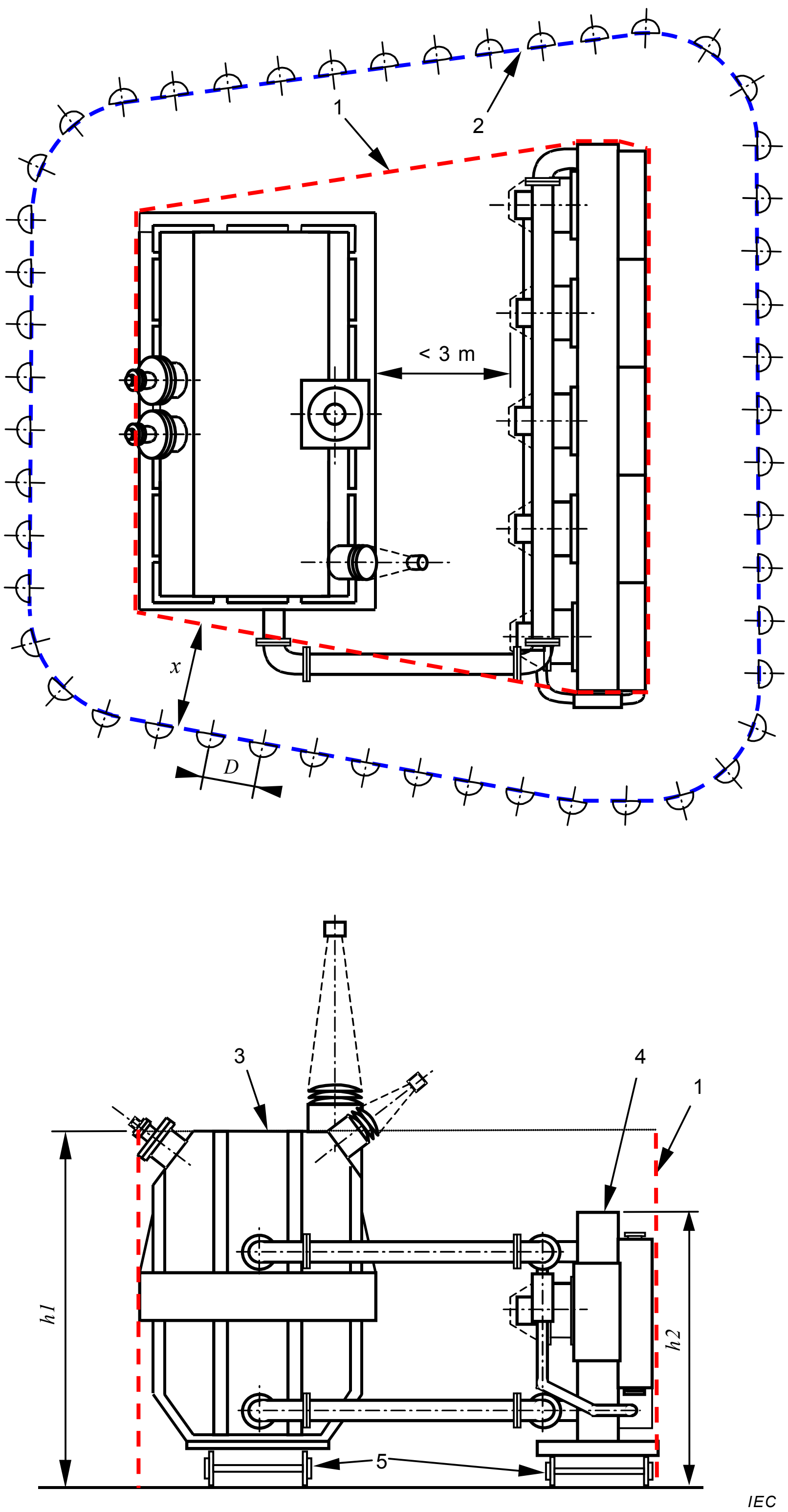
Figure 1 – Typical microphone path / positions for sound measurement on transformers excluding cooling devices



Key

1 Horizontal forced air cooling	5 Cable box	9 Vertical forced air cooling
2 Natural air cooling	6 Prescribed contour	*D* Microphone spacing (if applicable)
3 Turret	7 Principal radiating surface	*h* Height of the principal radiating surface; the larger of $h1$ and $h2$
4 Transformer tank	8 On-load tap-changer	*x* Measurement distance

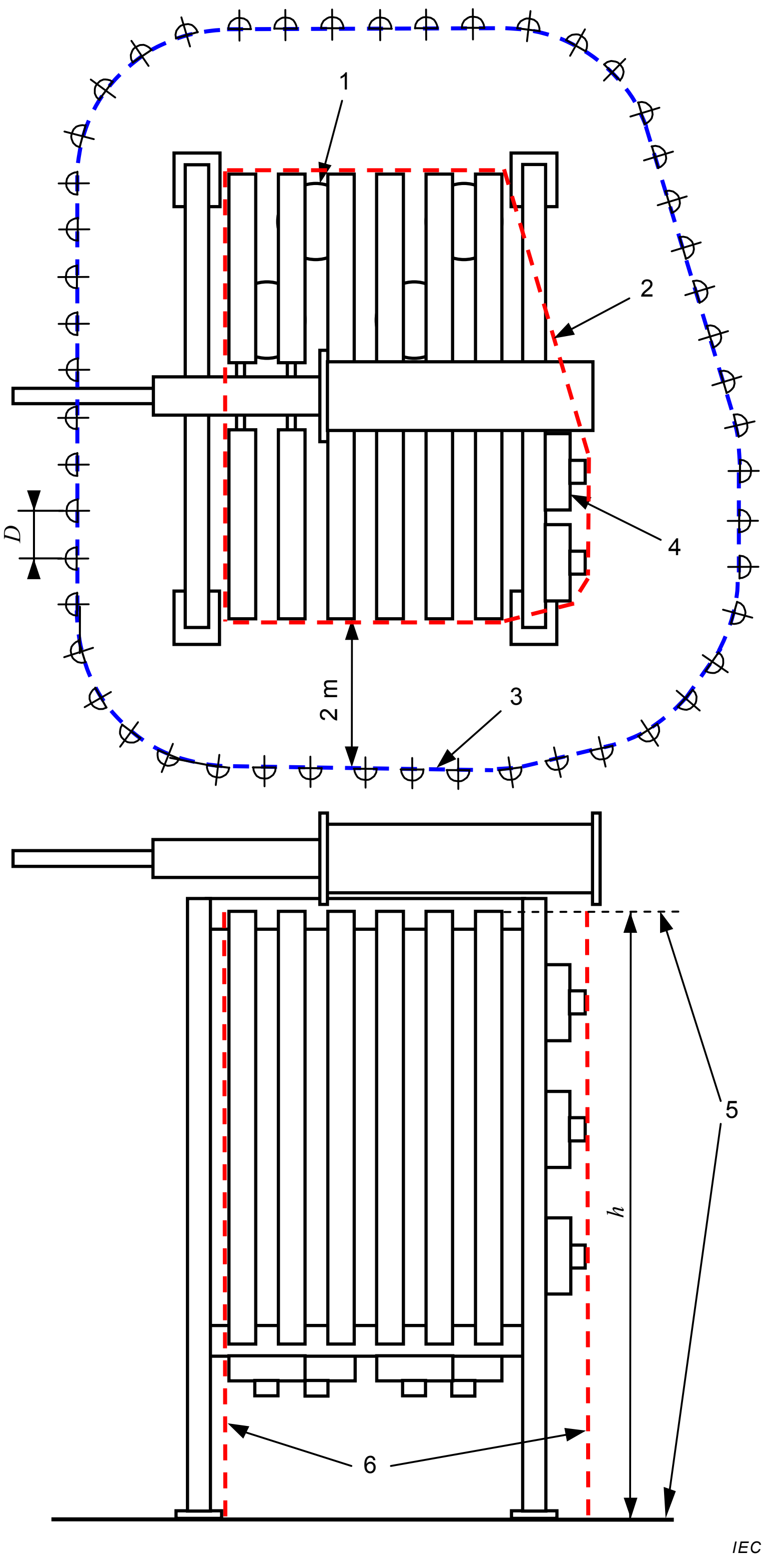
Figure 2 – Typical microphone path / positions for sound measurement on transformers having cooling devices mounted either directly on the tank or on a separate structure spaced < 3 m away from the principal radiating surface of the main tank



Key

1	Principal radiating surface	5	Support structure such as wheels, pallets, transportation car
2	Prescribed contour	*D*	Microphone spacing (if applicable)
3	Transformer tank	*h*	Height of the principal radiating surface; the larger of $h1$ and $h2$
4	Forced air cooling	*x*	Measurement distance

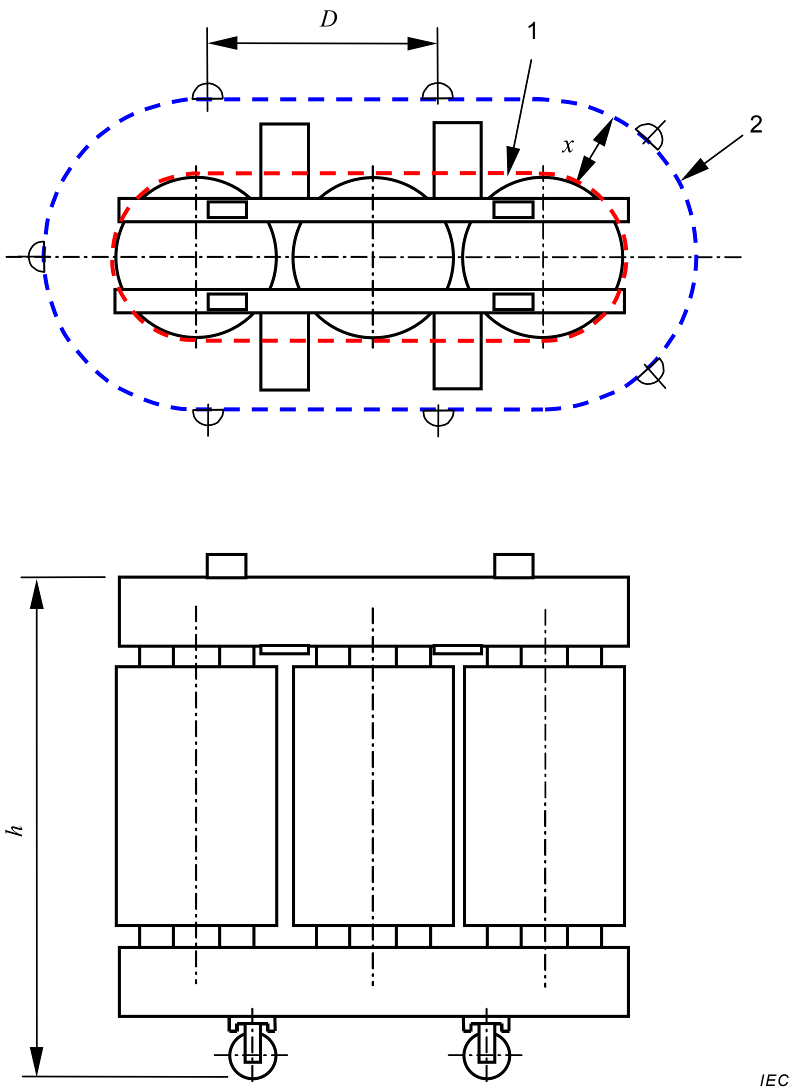
Figure 3 – Typical microphone path / positions for sound measurement on transformers having separate cooling devices spaced < 3 m away from the principal radiating surface of the main tank



Key

1 Vertical forced air cooling
2 Principal radiating surface
3 Prescribed contour
4 Horizontal forced air cooling
5 Horizontal boundaries of principal radiating surface
6 Vertical boundaries of principal radiating surface
D Microphone spacing (if applicable)
h Height of the principal radiating surface

Figure 4 – Typical microphone path / positions for sound measurement on cooling devices mounted on a separate structure spaced ≥ 3 m away from the principal radiating surface of the transformer



Key

1 Principal radiating surface

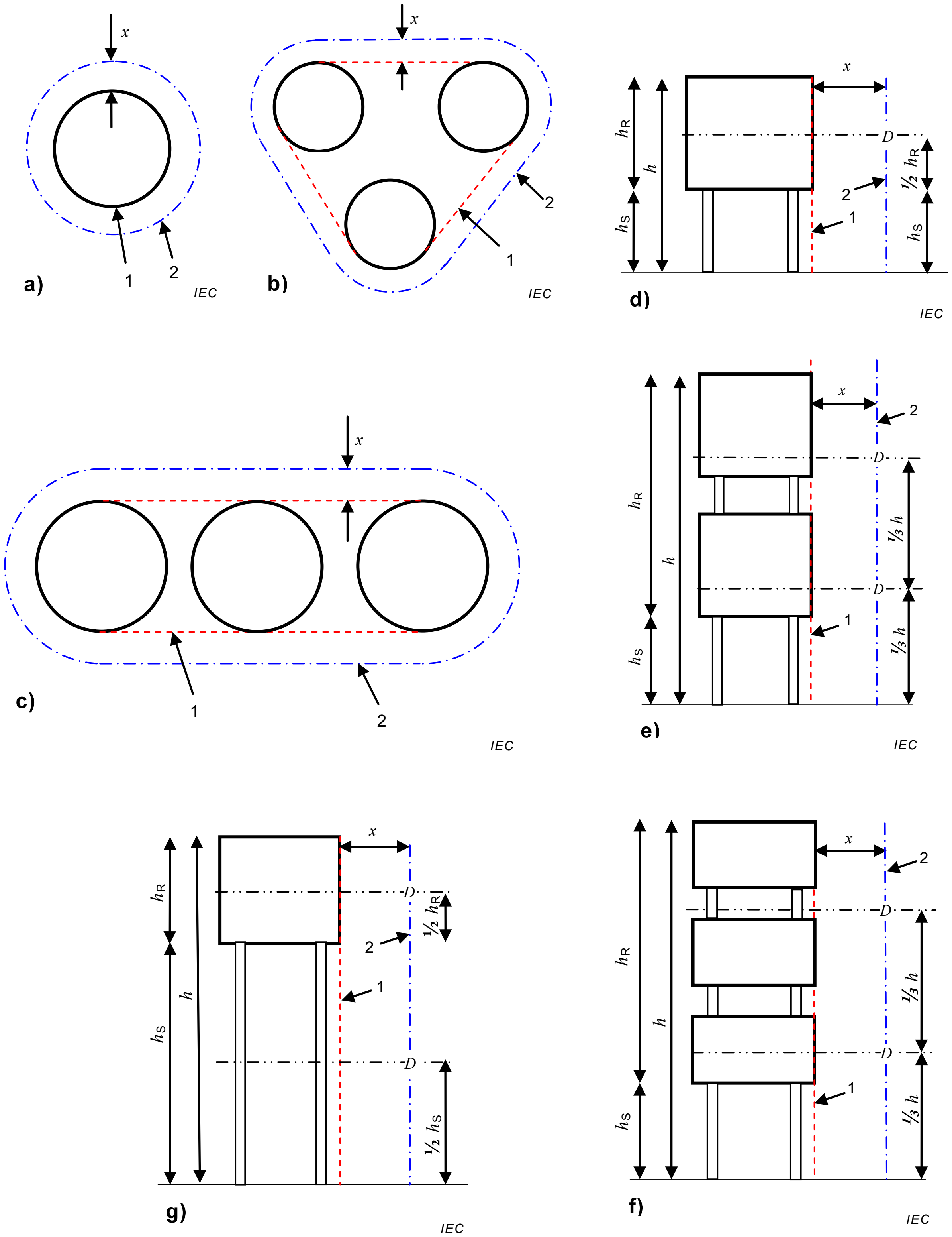
2 Prescribed contour

h Height of core with framework

D Microphone spacing (if applicable)

x Measurement distance

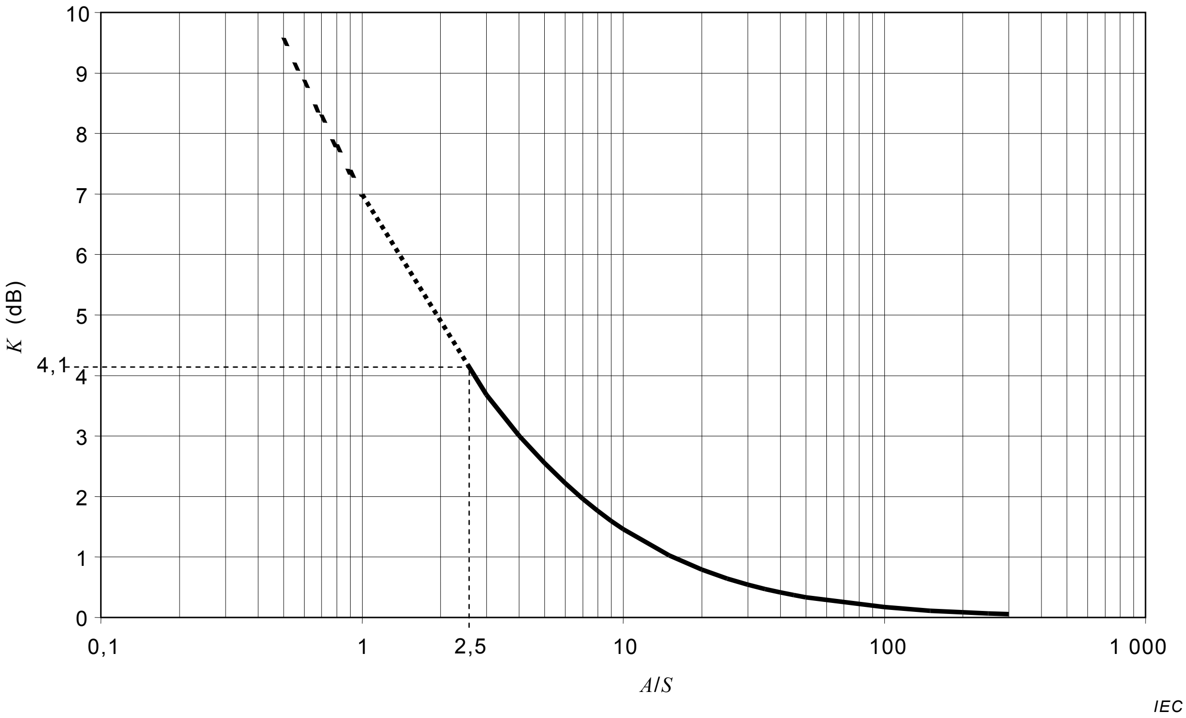
Figure 5 – Typical microphone positions for sound measurement on dry-type transformers without enclosures



Key

1	Principal radiating surface	h_S	Height of support structure
2	Prescribed contour	h_R	Height of coil or coil stack
D	Vertical microphone positions	h	Height of reactor – sum of h_R and h_S
x	Measurement distance		

Figure 6 – Principle radiating surface and prescribed contour of dry-type air-core reactors



$$K = 10 \times \lg\left(1 + \frac{4}{A/S}\right)$$

Figure 7 – Environmental correction, *K*

Annex A
(informative)

Narrow-band and time-synchronous measurements

A.1 General considerations

Transformer sound is characterized by tones at double the power frequency and at even harmonics of the power frequency whereas cooling device sound is predominantly broadband in its nature.

To demonstrate and measure the tonal components either narrow-band or time-synchronous measurement techniques may be used.

NOTE Sound level measurements as per this standard do not evaluate tonality. This is strictly a matter when overall levels of noise are assessed at the receiver.

For time-synchronous measurements, frequency components in-between the tones will be suppressed whereas this does not apply for narrow-band measurements.

In circumstances where background noise levels lead to invalid results according to criteria laid down in 11.2 and 11.3, narrow-band or time-synchronous measurements may offer a way to filter out unwanted signals. For narrow-band measurements tonal components shall be separated from the whole signal and summed up by post-processing whereas this is not necessary for time-synchronous measurements.

The effects of reflections described by the environmental correction K cannot be eliminated by either of the above techniques.

The choice of an alternative measurement method is subject to agreement between manufacturer and purchaser.

These methods are applicable for sound pressure and sound intensity measurements and can be used to calculate sound power levels.

A.2 Narrow-band measurement

A.2.1 General

Two narrow-band techniques are currently available, Fast Fourier Transform (FFT) based processing algorithms providing a constant bandwidth and digital filter based processing algorithms providing constant relative bandwidth (1/n-octave) and both are acceptable.

The permitted variation of the excitation frequency will lead to shifts of the harmonic frequencies which may result in frequencies of interest falling out of preselected narrow bands (between narrow bands). If the above applies one can either increase the bandwidth or use post-processing techniques to account for this. For more information see IEC 60076-10-1:2016.

Narrow-band measurements can be used for all loading conditions described in this standard, provided all narrow bands present within the frequency range of the measurement are included in the summation to determine the final sound level.

Narrow-band measurements apply equally to both the walk-around procedure and the point-by-point procedure.

It is important to consider the frequency range of the measuring device since limited frequency range may eliminate required signals.

A.2.2 Post processing of narrow-band measurements to exclude background noise

High or non-steady-state background noise can be mitigated by the use of narrow-band techniques. For this purpose relevant tones only will be evaluated in the summation and in this case cooling devices should be out of service to take full advantage of the technique.

Where odd harmonics of excitation frequencies are present as mentioned in 4.2 and 11.1.2 the narrow band measurement shall not be used to mitigate their presence.

The total A-weighted sound pressure level can be calculated using Equation (24), where L_1, $L_2 ... L_n$ are the measured A-weighted sound pressure levels of the bands, centred on frequencies $2 \times f \times \nu$. ν is the sequence number of multiples of the even harmonics of the excitation frequency f running from 1 to n.

Corrections due to factor K apply as described in 11.2.5.

The total A-weighted sound intensity level can be calculated using Equations (25) and (26), where L_1, $L_2 ... L_n$ are the measured A-weighted sound intensity levels of the bands, centred on frequencies $2 \times f \times \nu$. ν is the sequence number of multiples of the even harmonics of the excitation frequency f running from 1 to n.

NOTE The summation of sound levels for the first 10 bands is adequate for most transformers operating at almost sinusoidal voltage and current. However, in the presence of harmonics in voltage and/or current, higher frequencies can contribute significantly to the total sound level. In this case, higher order frequency bands are to be included.

A.3 Time-synchronous averaging technique

Time-synchronous averaging is an averaging of digitized time records of the sound signal, the start of which is defined by a repetitive trigger signal.

This technique is intended to measure signals which are phase correlated to the trigger (usually the excitation voltage). Non-correlated signals will therefore be suppressed. Therefore, such techniques are suitable for measurement of transformer sound only. Sound emitted from cooling devices cannot be measured with such techniques.

NOTE 1 Background noise due to industrial sound sources can also be synchronous. A common example would be a test transformer which cannot be turned off. In these cases, the use of this method may not be entirely appropriate.

Time-synchronous measurements are only valid for the point-by-point procedure. This technique is strictly inappropriate for the walk-around procedure.

NOTE 2 The attenuation of the background noise depends on the number of averages, n, that are included in the measurement. The signal-to-noise ratio improvement in dB is given by $S/N = 10 \times \lg (n^{0.5})$.

Annex B
(informative)

Typical report of sound level determination

B.1 Sound pressure method

Sound pressure method **Report No.: ABC-123**

Sound level measurement
Transformer

Type:	
Purchaser:	**Standard:** ***IEC 60076-10:2016***
Order No.:	**Serial No.:**
Rated power: ***450 MVA***	**Rated frequency:** ***60 Hz***
Engineer:	**Date of test:** ***2015-04-15***

Measuring instruments	**Manufacturer**	**Type**	**Serial No.**
Sound level meter	xyz	2815	25051971
Sound level calibrator	xyz	5432	990707
Software version		1.0	

☒ The equipment used has been laboratory calibrated in accordance with manufacturers recommendations and field calibrated before and after each measurement session

Application details:

- ***sound pressure method***
- ***walk-around procedure***
- ***1/3 octave band***
- ***environmental correction K based on the measured sound absorption area as per test certificate TAC 121-04, dated 28.10.2009***

Measurement reason: ***Final Acceptance Test (FAT)***

Measurement location: ***Test lab A***

☒ **Sound power level** L_{WA}

☐ **Sound pressure level** $\overline{L_{pA}}$ **at measuring distance**

☐ **Sound pressure level** $\overline{L_{pA}}$ **at a specified distance (derived from sound power)**

Rated voltage [%]	Rated current [%]	Tap position	Distance [m] (not applicable for sound power level)	In operation		Sound level [dB(A)]	
				No. of fans	No. of pumps	Guaranteed	Calculated from measurements*
100	60	7				90	85
100	100	7		32	2	100	100

* See calculation on page 2

Sound pressure method **Report No.: ABC-123**

Calculations from measurements

☒ **Sound power level** L_{WA}

☐ **Sound pressure level** $\overline{L_{pA}}$ **at the measuring distance**

☐ **Sound pressure level** $\overline{L_{pA}}$ **at a specified distance (derived from sound power)**

		No-load	Load	Cooling device	Final sound level (Sum of sound components)
Page ref.		5	6		
Rated voltage [%]		100			100
Rated current [%]			60		60
Tap position			7		7
Fans in operation					
Pumps in operation					
Distance [m]		n.a.	n.a.		n.a.
Frequency [Hz]		**[dB(A)]**	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**
Total sound level		**78,9**	**84,1**		**85,2**
Octave band	63				
	125				
	250				
	500				
	1 000				
	2 000				
	4 000				
	8 000				
1 / 3 Octave band	50	52,8	47,3		**53,9**
	63	56,7	51,9		**58,0**
	80	58,5	54,2		**59,9**
	100	57,6	68,3		**68,6**
	125	67,3	81,0		**81,2**
	160	60,8	60,8		**63,9**
	200	57,3	58,6		**61,0**
	250	66,6	71,4		**72,6**
	315	69,7	67,6		**71,7**
	400	73,5	69,2		**74,9**
	500	66,2	67,8		**70,1**
	630	67,1	66,6		**69,9**
	800	66,7	65,9		**69,4**
	1 000	68,5	0,0		**68,5**
	1 250	64,3	67,5		**69,2**
	1 600	66,2	71,2		**72,4**
	2 000	63,9	71,3		**72,0**
	2 500	64,5	68,4		**69,9**
	3 150	0,0	69,1		**69,1**
	4 000	0,0	0,0		**3,0**
	5 000	0,0	67,4		**67,4**
	6 300	0,0	69,7		**69,7**
	8 000	0,0	71,4		**71,4**
	10 000	0,0	68,2		**68,2**

		No-load	Load	Cooling device	Final sound level (Sum of sound components)
Page ref.		5	7		
Rated voltage [%]		100			100
Rated current [%]			100		100
Tap position			7		7
Fans in operation			32		32
Pumps in operation			2		2
Distance [m]		n.a.	n.a		n.a.
Frequency [Hz]		**[dB(A)]**	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**
Total sound level		**78,9**	**100,1**		**100,1**
Octave band	63				
	125				
	250				
	500				
	1 000				
	2 000				
	4 000				
	8 000				
1 / 3 Octave band	50	52,8	49,1		**54,3**
	63	56,7	55,4		**59,1**
	80	58,5	64,3		**65,3**
	100	57,6	79,4		**79,4**
	125	67,3	90,5		**90,5**
	160	60,8	79,7		**79,8**
	200	57,3	81,2		**81,2**
	250	66,6	85,0		**85,1**
	315	69,7	87,8		**87,9**
	400	73,5	89,7		**89,8**
	500	66,2	88,3		**88,3**
	630	67,1	88,4		**88,4**
	800	66,7	90,0		**90,0**
	1 000	68,5	89,9		**89,9**
	1 250	64,3	90,3		**90,3**
	1 600	66,2	89,2		**89,2**
	2 000	63,9	88,2		**88,2**
	2 500	64,5	85,8		**85,8**
	3 150	0,0	83,6		**83,6**
	4 000	0,0	80,4		**80,4**
	5 000	0,0	79,1		**79,1**
	6 300	0,0	78,5		**78,5**
	8 000	0,0	77,6		**77,6**
	10 000	0,0	73,9		**73,9**

Page **2** of **8**

Sound pressure method **Report No.: ABC-123**

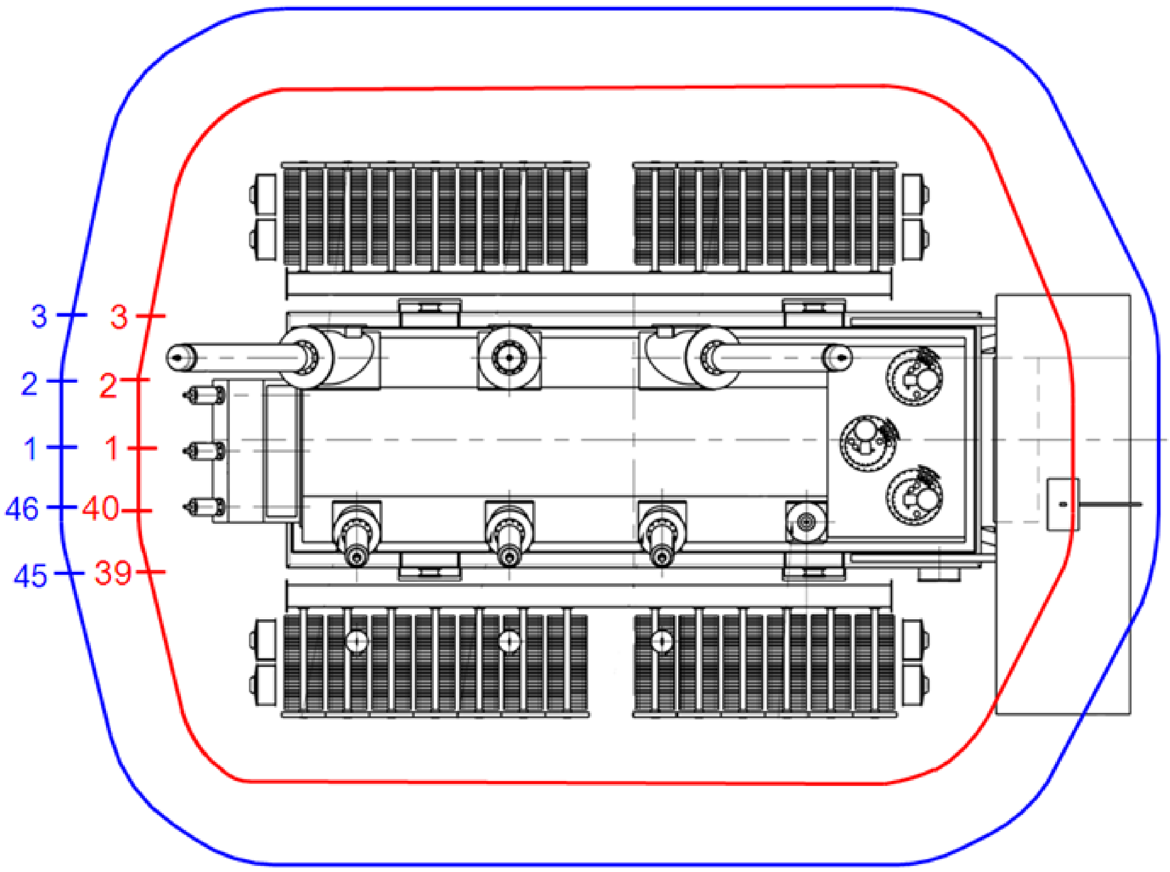
Symbols and equations

initial $\overline{L_{bgA}}$	…	*average A-weighted background noise level before test measurement* $\overline{L_{bgA}} = 10 \times lg\left(\frac{1}{M}\sum_{i=1}^{M} 10^{0,1 L_{bgAi}}\right)$, applies to each frequency band $\overline{L^{\nu}_{bgA}}$	dB(A)
final $\overline{L_{bgA}}$	…	*average A-weighted background noise level after test measurement* $\overline{L_{bgA}} = 10 \times lg\left(\frac{1}{M}\sum_{i=1}^{M} 10^{0,1 L_{bgAi}}\right)$, applies to each frequency band $\overline{L^{\nu}_{bgA}}$	dB(A)
$\overline{L_{pA0}}$	…	*uncorrected average A-weighted sound pressure level* $\overline{L_{pA0}} = 10 \times lg\left(\frac{1}{N}\sum_{i=1}^{N} 10^{0,1 L_{pAi}}\right)$, applies to each frequency band $\overline{L^{\nu}_{pA0}}$	dB(A)
$\overline{L_{pA}}$	…	*corrected average A-weighted sound pressure level* $\overline{L_{pA}} = 10 \times \lg\left(10^{0,1\overline{L_{pA0}}} - 10^{0,1\overline{L_{bgA}}}\right) - K$, applies to each frequency band $\overline{L^{\nu}_{pA}}$ $\overline{L_{bgA}}$ is *the lower of the two average A-weighted background sound pressure levels*	dB(A)
K	…	*environmental correction* $K = 10 \times \lg\left(1 + \frac{4}{A/S}\right)$	dB
A	…	*sound absorbing area* $A = 0{,}16 \frac{V}{T}$	m²
T	…	*reverberation time*	s
V	…	*volume of test room*	m³
S	…	*area of measurement surface (surface area)* $S = (h + x) l_m$ h *– height of principal radiating surface;* x *– measurement distance;* l_m *– length of prescribed contour*	m² m
L_S	…	*surface measure in dB* $L_S = 10 \times \lg \frac{S}{S_0}$	dB
L_{WA}	…	*A-weighted sound power level (calculation from corrected spatially averaged A-weighted sound pressure level* $\overline{L_{pA}}$ *):* $L_{WA} = \overline{L_{pA}} + 10 \times \lg \frac{S}{S_0}$, applies to each frequency band $\overline{L^{\nu}_{WA}}$	dB(A)
L_{sum}	…	*logarithmic addition for sound levels* $L_{sum} = 10 \times \lg\left(10^{0,1L_1} + 10^{0,1L_2} + ... + 10^{0,1L_n}\right)$	dB(A)

Sound pressure method **Report No.: ABC-123**

Prescribed contours

x Distance [m]	l_m Prescribed contour [m]	h Height [m]	S Surface area [m^2]	L_S Surface measure [dB]
1	40	5,9	276	24,4
2	46	5,9	363	25,6



Sound pressure method — Report No.: ABC-123

Measurement 1

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m²]	Surface measure [dB]
			Fans	Pumps						
100					**60**	**1**	**40**	**5,9**	**276**	**24,4**

Measurement duration [s]: 155

Frequency		initial $\overline{L_{bgA}}$	final $\overline{L_{bgA}}$	initial $\overline{L_{bgA}}$ – final $\overline{L_{bgA}}$	$\overline{L_{pA0}}$	$\overline{L_{pA0}}$ – higher $\overline{L_{bgA}}$	A^*	K	$\overline{L_{pA}}$	L_{WA}
[Hz]		[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[m²]	[dB]	[dB(A)]	[dB(A)]
Total sound level		**50,9**	**53,0**	**-2,1**	**56,8**	**3,8**			**54,5**	**78,9**
Octave band	63									
	125									
	250									
	500									
	1 000									
	2 000									
	4 000									
	8 000									
1 / 3 Octave band	50	26,2	24,4	1,8	31,3		2 000	1,9	28,4	**52,8**
	63	28,7	24,5	4,2	34,6		2 105	1,8	32,3	**56,7**
	80	30	26,2	3,8	36,3		2 216	1,8	34,1	**58,5**
	100	28,2	25,6	2,6	35,4		2 333	1,7	33,2	**57,6**
	125	28,6	29	-0,4	44,6		2 455	1,6	42,9	**67,3**
	160	29,8	32,2	-2,4	38,6		2 585	1,5	36,4	**60,8**
	200	31,8	32,7	-0,9	36,3		2 721	1,5	32,9	**57,3**
	250	32,4	34	-1,6	43,9		2 864	1,4	42,2	**66,6**
	315	32,9	36,7	-3,8	46,8		3 015	1,4	45,3	**69,7**
	400	33,3	38,1	-4,8	50,5		3 173	1,3	49,1	**73,5**
	500	36,6	39,4	-2,8	43,9		3 340	1,2	41,8	**66,2**
	630	39,3	42,5	-3,2	45,2		3 516	1,2	42,7	**67,1**
	800	40,7	44	-3,3	45,3		3 701	1,1	42,3	**66,7**
	1 000	41,5	45,1	-3,6	46,7		3 896	1,1	44,1	**68,5**
	1 250	41,2	43,3	-2,1	44,1		4 101	1,0	39,9	**64,3**
	1 600	39,7	43,1	-3,4	44,5		4 317	1,0	41,8	**66,2**
	2 000	39,2	39,4	-0,2	42,9		4 544	0,9	39,5	**63,9**
	2 500	41,4	36,8	4,6	42,4		4 783	0,9	40,1	**64,5**
	3 150	39,5	41,5	-2	38,8	-2,7	5 035	0,9	0,0	**0,0**
	4 000	36,9	42,9	-6	33,8	-9,1	5 300	0,8	0,0	**0,0**
	5 000	37,2	33,3	3,9	32,6	-4,6	5 431	0,8	0,0	**0,0**
	6 300	37	34,9	2,1	31,9	-5,1	5 579	0,8	0,0	**0,0**
	8 000	35,1	29,6	5,5	30,1	-5,0	5 873	0,7	0,0	**0,0**
	10 000	27,8	21,5	6,3	27,1	-0,7	6 182	0,7	0,0	**0,0**

* if there is only one value for the sound absorbing area available, this value applies to all frequencies

$\overline{L_{pA0}}$ – higher $\overline{L_{bgA}}$	inital $\overline{L_{bgA}}$ – final $\overline{L_{bgA}}$	Decision
≥ 8 dB	-	Accept test
< 8 dB	< 3 dB	Accept test
< 8 dB	> 3 dB	Repeat test [a]
< 3 dB	-	Repeat test [a]

[a] Unless $\overline{L_{pA0}}$ meets the guarantee.

Correction for background noise is not required in this case and the test is declared a pass

Sound pressure method — Report No.: ABC-123

Measurement 2

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m²]	Surface measure [dB]
			Fans	Pumps						
	60	**7**			**60**	**1**	**40**	**5,9**	**276**	**24,4**

Measurement duration [s]: 142

	Frequency	initial $\overline{L_{bgA}}$	final $\overline{L_{bgA}}$	initial $\overline{L_{bgA}}$ – final $\overline{L_{bgA}}$	$\overline{L_{pA0}}$	$\overline{L_{pA0}}$ – higher $\overline{L_{bgA}}$	A^*	K	$\overline{L_{pA}}$	L_{WA}
	[Hz]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[m²]	[dB]	[dB(A)]	[dB(A)]
Total sound level		**50,8**	**53,1**	**-2,3**	**61,5**	**8,4**			**59,7**	**84,1**
Octave band	63									
	125									
	250									
	500									
	1 000									
	2 000									
	4 000									
	8 000									
1 / 3 Octave band	50	26,2	24,4	1,8	27,6		2 000	1,9	22,9	**47,3**
	63	28,7	24,5	4,2	30,6		2 105	1,8	27,5	**51,9**
	80	30	26,2	3,8	32,7		2 216	1,8	29,8	**54,2**
	100	28,2	25,6	2,6	45,6		2 333	1,7	43,9	**68,3**
	125	28,6	29	-0,4	58,2		2 455	1,6	56,6	**81,0**
	160	29,8	32,2	-2,4	38,6		2 585	1,5	36,4	**60,8**
	200	31,8	32,7	-0,9	37,2		2 721	1,5	34,2	**58,6**
	250	32,4	34	-1,6	48,5		2 864	1,4	47,0	**71,4**
	315	32,9	36,7	-3,8	44,8		3 015	1,4	43,2	**67,6**
	400	33,3	38,1	-4,8	46,3		3 173	1,3	44,8	**69,2**
	500	36,6	39,4	-2,8	45,3		3 340	1,2	43,4	**67,8**
	630	39,3	42,5	-3,2	44,8		3 516	1,2	42,2	**66,6**
	800	40,7	44	-3,3	44,8		3 701	1,1	41,5	**65,9**
	1 000	41,5	45,1	-3,6	43,6	-1,5	3 896	1,1	0,0	**0,0**
	1 250	41,2	43,3	-2,1	45,9		4 101	1,0	43,1	**67,5**
	1 600	39,7	43,1	-3,4	48,4		4 317	1,0	46,8	**71,2**
	2 000	39,2	39,4	-0,2	48,4		4 544	0,9	46,9	**71,3**
	2 500	41,4	36,8	4,6	45,5		4 783	0,9	44,0	**68,4**
	3 150	39,5	41,5	-2	46,5		5 035	0,9	44,7	**69,1**
	4 000	36,9	42,9	-6	42,1	-0,8	5300	0,8	0,0	**0,0**
	5 000	35	39,9	-4,9	44,3		5 431	0,8	43,0	**67,4**
	6 300	37	34,9	2,1	46,4		5 579	0,8	45,3	**69,7**
	8 000	35,1	29,6	5,5	47,8		5 873	0,7	47,0	**71,4**
	10 000	27,8	21,5	6,3	44,5		6 182	0,7	43,8	**68,2**

* If there is only one value for the sound absorbing area available, this value applies to all frequencies

$\overline{L_{pA0}}$ – *supérieure* $\overline{L_{bgA}}$	*initale* $\overline{L_{bgA}}$ – *finale* $\overline{L_{bgA}}$	Decision	
≥ 8 dB	-	Accept test	[a] Unless $\overline{L_{pA0}}$ meets the guarantee.
< 8 dB	< 3 dB	Accept test	Correction for background noise is not required in this case and the test is declared a pass
< 8 dB	> 3 dB	Repeat test [a]	
< 3 dB	-	Repeat test [a]	

Page **6** of **8**

Sound pressure method — Report No.: ABC-123

Measurement 3

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m^2]	Surface measure [dB]
			Fans	Pumps						
	100	**7**	**32**	**2**	**60**	**2,0**	**46**	**5,9**	**363**	**25,6**

Measurement duration [s]: 181

Frequency		initial $\overline{L_{bgA}}$	final $\overline{L_{bgA}}$	initial $\overline{L_{bgA}}$ – final $\overline{L_{bgA}}$	$\overline{L_{pA0}}$	$\overline{L_{pA0}}$ – higher $\overline{L_{bgA}}$	A^*	K	$\overline{L_{pA}}$	L_{WA}
[Hz]		[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[m^2]	[dB]	[dB(A)]	[dB(A)]
Total sound level		**51,0**	**53,2**	**-2,2**	**76,0**	**22,8**			**74,5**	**100,1**
Octave band	63									
	125									
	250									
	500									
	1000									
	2000									
	4000									
	8000									
1 / 3 Octave band	50	26,2	24,4	1,8	28,2		2 000	2,4	23,5	**49,1**
	63	28,7	24,5	4,2	32,8		2 105	2,3	29,8	**55,4**
	80	30	26,2	3,8	41		2 216	2,2	38,7	**64,3**
	100	28,2	25,6	2,6	55,9		2 333	2,1	53,8	**79,4**
	125	28,6	29	-0,4	66,9		2 455	2,0	64,9	**90,5**
	160	29,8	32,2	-2,4	56		2 585	1,9	54,1	**79,7**
	200	31,8	32,7	-0,9	57,5		2 721	1,9	55,6	**81,2**
	250	32,4	34	-1,6	61,2		2 864	1,8	59,4	**85,0**
	315	32,9	36,7	-3,8	63,9		3 015	1,7	62,2	**87,8**
	400	33,3	38,1	-4,8	65,7		3 173	1,6	64,1	**89,7**
	500	36,6	39,4	-2,8	64,3		3 340	1,6	62,7	**88,3**
	630	39,3	42,5	-3,2	64,3		3 516	1,5	62,8	**88,4**
	800	40,7	44	-3,3	65,9		3 701	1,4	64,4	**90,0**
	1 000	41,5	45,1	-3,6	65,7		3 896	1,4	64,3	**89,9**
	1 250	41,2	43,3	-2,1	66		4 101	1,3	64,7	**90,3**
	1 600	39,7	43,1	-3,4	64,9		4 317	1,3	63,6	**89,2**
	2 000	39,2	39,4	-0,2	63,8		4 544	1,2	62,6	**88,2**
	2 500	41,4	36,8	4,6	61,4		4 783	1,2	60,2	**85,8**
	3 150	39,5	41,5	-2	59,1		5 035	1,1	58,0	**83,6**
	4 000	36,9	42,9	-6	55,9		5 300	1,1	54,8	**80,4**
	5 000	38,2	41,5	-3,3	54,6		5 431	1,0	53,5	**79,1**
	6 300	37	34,9	2,1	54		5 579	1,0	52,9	**78,5**
	8 000	35,1	29,6	5,5	53		5 873	1,0	52,0	**77,6**
	10 000	27,8	21,5	6,3	49,2		6 182	0,9	48,3	**73,9**

* If there is only one value for the sound absorbing area available, this value applies to all frequencies

$\overline{L_{pA0}}$ – *supérieure* $\overline{L_{bgA}}$	*initale* $\overline{L_{bgA}}$ – *finale* $\overline{L_{bgA}}$	Decision
≥ 8 dB	-	Accept test
< 8 dB	< 3 dB	Accept test
< 8 dB	> 3 dB	Repeat test [a]
< 3 dB	-	Repeat test [a]

[a] Unless $\overline{L_{pA0}}$ meets the guarantee.

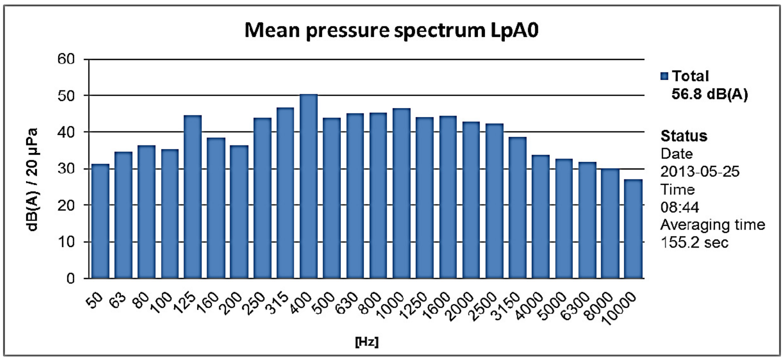
Correction for background noise is not required in this case and the test is declared a pass

Sound pressure method **Report No.: ABC-123**

Measurement graphs

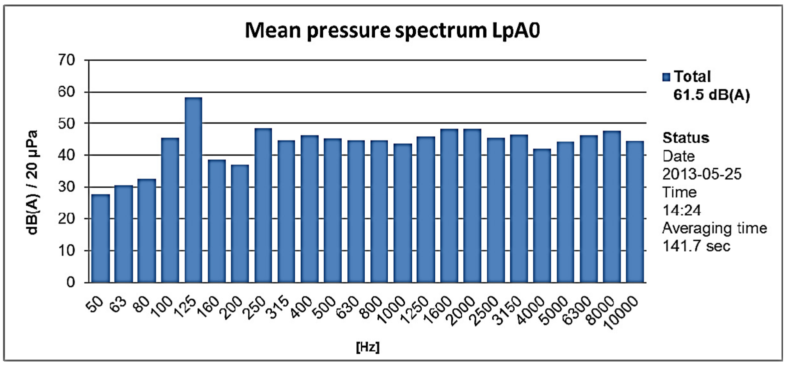
Measurement 1

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m^2]	Surface measure [dB]
			Fans	Pumps						
100					60	1	40	5,9	276	24,4



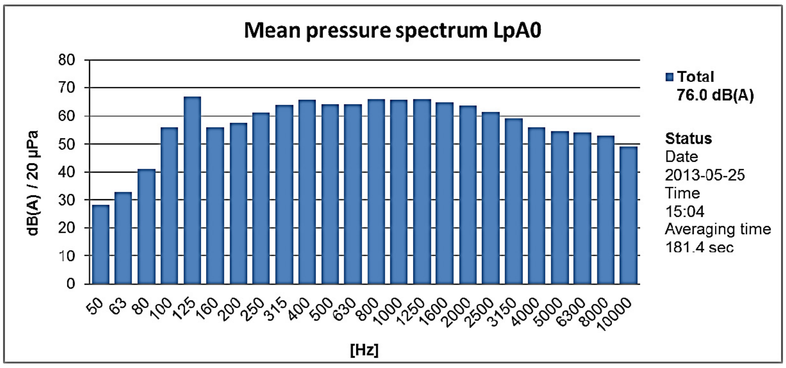
Measurement 2

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m^2]	Surface measure [dB]
			Fans	Pumps						
	60	7			60	1	40	5,9	276	24,4



Measurement 3

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m^2]	Surface measure [dB]
			Fans	Pumps						
	100	7	32	2	60	2	46	5,9	363	25,6



B.2 Sound pressure method – Appendix for the point-by-point procedure

Sound pressure method **Report No.: ABC-123**

Measurement 3

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m²]	Surface measure [dB]
			Fans	Pumps						
	100	7	32	2	60	2,0	46	5,9	363	25,6

Average measurement duration per point [s]: 3

Path at 1/3 of test object height, Points 1-6 of 46

		Path 1/3 **Point 01** / 46	Path 1/3 **Point 02** / 46	Path 1/3 **Point 03** / 46	Path 1/3 **Point 04** / 46	Path 1/3 **Point 05** / 46	Path 1/3 **Point 06** / 46
Frequency		L_{pAi}	L_{pAi}	L_{pAi}	L_{pAi}	L_{pAi}	L_{pAi}
[Hz]		**[dB(A)]**	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**
Total sound level							
Octave band	63						
	125						
	250						
	500						
	1 000						
	2 000						
	4 000						
	8 000						
1 / 3 Octave band	50						
	63						
	80						
	100						
	125						
	160						
	200						
	250						
	315						
	400						
	500						
	630						
	800						
	1 000						
	1 250						
	1 600						
	2 000						
	2 500						
	3 150						
	4 000						
	5 000						
	6 300						
	8 000						
	10 000						

B.3 Sound intensity method

Sound intensity method **Report No.: DEF-456**

Sound level measurement
Transformer

Type:	
Purchaser:	**Standard:** ***IEC 60076-10:2016***
Order No.:	**Serial No.:**
Rated Power: 67*0 MVA*	**Rated frequency:** ***50 Hz***
Engineer:	**Date of test:** ***2015-04-15***

Measuring Instruments	**Manufacturer**	**Type**	**Serial No.**
Sound level meter	xyz	9876	19031963
Sound level calibrator	xyz	5432	990707
Software version		1.3	
Spacer distance between microphones		50 mm	

☒ The equipment used has been laboratory calibrated in accordance with manufacturers recommendations and field calibrated before and after each measurement session

Application details:

– ***sound intensity method***
– ***walk-around procedure***
– ***1/3 octave band***

Measurement reason: ***Final Acceptance Test (FAT)***

Measurement location: ***Test lab B***

☒ **Sound power level** L_{WA}

☐ **Sound intensity level** $\overline{L_{IA}}$ **at the measuring distance**

☐ **Sound pressure level** $\overline{L_{pA}}$ **at a specified distance (derived from sound power)**

Rated voltage [%]	Rated current [%]	Tap position	Distance [m] (not applicable for sound power level)	In operation		Sound level [dB(A)]	
				No. of fans	No. of pumps	Guaranteed	Calculated from measurements*
100				0		87	87
100	100	1		24		92	91

* See calculation on Page 2

Sound intensity method — Report No.: DEF-456

Calculations from measurements

☒ **Sound power level** L_{WA}

☐ **Sound pressure level** $\overline{L_{pA}}$

☐ **Sound intensity level** $\overline{L_{IA}}$

derived from sound intensity level $\overline{L_{IA}}$

		No-load	Load	Cooling device	Final sound level (Sum of components)
Page ref.		5			
Rated voltage [%]		100			100
Rated current [%]					
Tap position					
Fans in operation		0			0
Pumps in operation					
Distance [m]		n.a.			n.a.
Frequency [Hz]		[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]
Total sound level		**87,2**			**87,2**
Octave band	63				
	125				
	250				
	500				
	1 000				
	2 000				
	4 000				
	8 000				
1 / 3 Octave band	50	0			**0**
	63	0			**0**
	80	60.0			**60.0**
	100	74,6			**74,6**
	125	57,7			**57,7**
	160	63,1			**63,1**
	200	75,3			**75,3**
	250	68,4			**68,4**
	315	85,1			**85,1**
	400	77,9			**77,9**
	500	73,8			**73,8**
	630	69,6			**69,6**
	800	63,4			**63,4**
	1 000	62,7			**62,7**
	1 250	64,4			**64,4**
	1 600	0			**0**
	2 000	0			**0**
	2 500	67.0			**67.0**
	3 150	0			**0**
	4 000	64,9			**64,9**
	5 000	61,5			**61,5**
	6 300	56,8			**56,8**
	8 000	61,1			**61,1**
	10 000	51,8			**51,8**

		No-load	Load	Cooling device	Final sound level (Sum of components)
Page ref.		5	6	7	
Rated voltage [%]		100			100
Rated current [%]			100		100
Tap position			1		1
Fans in operation		0	0	24	24
Pumps in operation					
Distance [m]		n.a.	n.a.	n.a.	n.a.
Frequency [Hz]		[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]
Total sound level		**87,2**	**87,0**	**85,0**	**91,3**
Octave band	63				
	125				
	250				
	500				
	1 000				
	2 000				
	4 000				
	8 000				
1 / 3 Octave band	50	0	41,5	41,7	**44,6**
	63	0	73,7	51,8	**73,7**
	80	60.0	0	61,6	**63,9**
	100	74,6	85,3	63,0	**86,0**
	125	57,7	62,3	64,8	**67,0**
	160	63,1	66,0	66,1	**70,2**
	200	75,3	80,2	71,9	**82,7**
	250	68,4	66,9	73,3	**75,2**
	315	85,1	71,8	75,7	**84,7**
	400	77,9	66,3	75,3	**80,3**
	500	73,8	64,4	74,8	**77,4**
	630	69,6	57,6	74,7	**75,4**
	800	63,4	53,4	74,2	**74,5**
	1 000	62,7	53,5	73,3	**73,5**
	1 250	64,4	50,5	73,7	**73,9**
	1 600	0	0	72,6	**72,6**
	2 000	0	0	72,5	**72,5**
	2 500	67.0	44,8	70,8	**70,9**
	3 150	0	46,4	69,5	**69,5**
	4 000	64,9	40,0	66,1	**66,3**
	5 000	61,5	42,2	61,9	**62,1**
	6 300	56,8	39,1	57,4	**58,0**
	8 000	61,1	36,6	51,5	**52,6**
	10 000	51,8	35,6	54,4	**54,6**

Sound intensity method **Report No.: DEF-456**

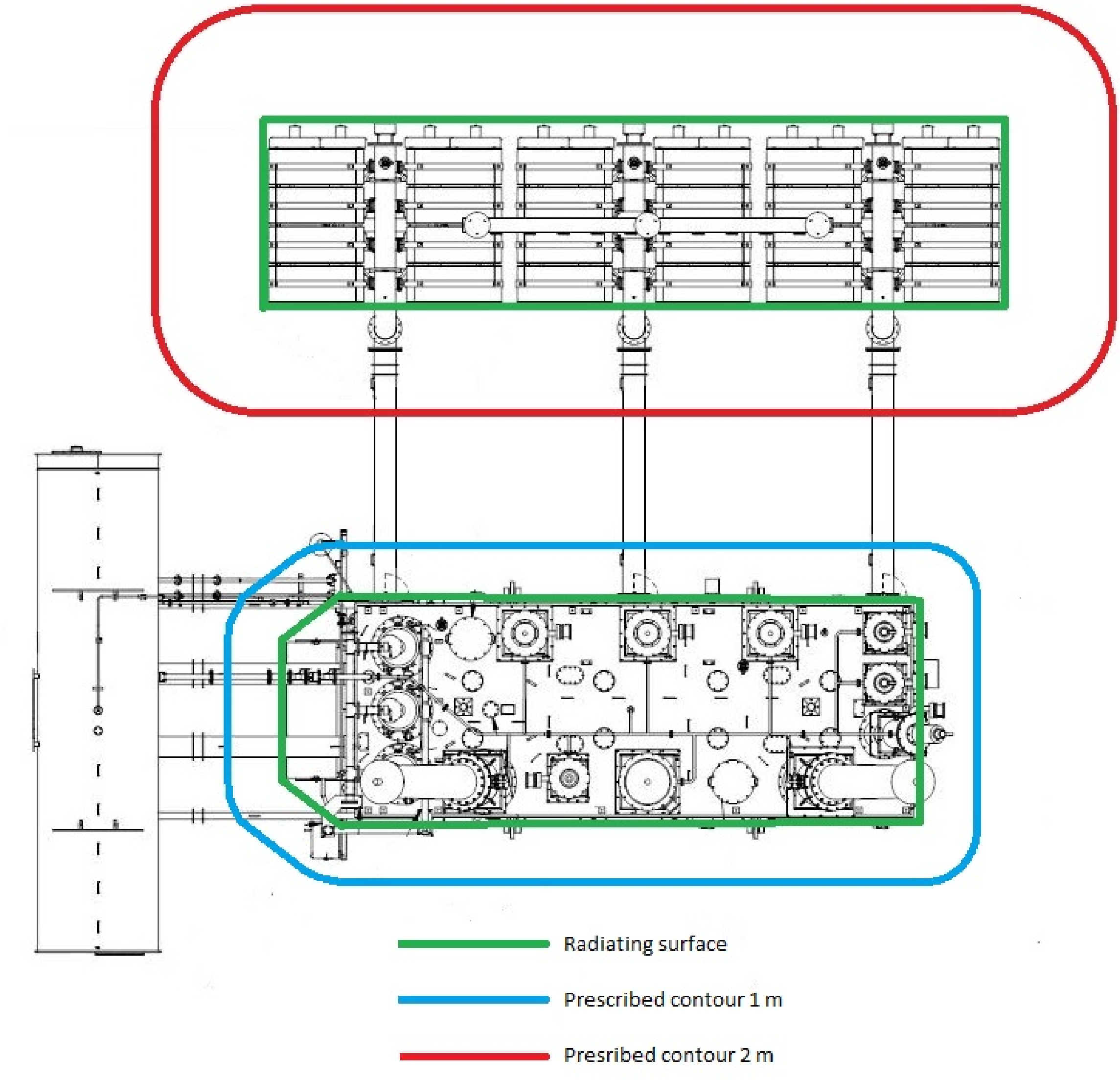
Symbols and equations

$\overline{L_{\text{pA0}}}$	…	*uncorrected average A-weighted sound pressure level* $\overline{L_{\text{pA0}}} = 10 \times lg\left(\frac{1}{N}\sum_{i=1}^{N} 10^{0,1 L_{\text{pAi}}}\right)$, applies to each frequency band $\overline{L^{\nu}_{\text{pA0}}}$	dB(A)
$\overline{L_{\text{IA0}}}$	…	*average A-weighted normal sound intensity level* $\overline{L_{\text{IA0}}} = 10 \times lg\left\lvert\frac{1}{N}\sum_{i=1}^{N} F_{\text{Diri}} \times 10^{0,1 L_{\text{IAi}}}\right\rvert$ *, applies to each frequency band* $\overline{L^{\nu}_{\text{IA0}}}$	dB(A)
F_{Diri}	…	*direction flag of the individual sound level i*	
$\overline{F_{\text{Dir}}}$	…	*direction flag indicating the net energy flow* $\overline{F_{\text{Dir}}} = Sign\left(\frac{1}{N}\sum_{i=1}^{N} F_{\text{Diri}} \times 10^{0,1 L_{\text{IAi}}}\right)$ *, applies to each frequency band* $\overline{F^{\nu}_{\text{Dir}}}$	
ΔL	…	*pressure-intensity index* $\Delta L = \overline{L_{\text{pA0}}} - \overline{L_{\text{IA0}}}$ *, applies to the total sound level only*	dB(A)
$\overline{L_{\text{IA}}}$	…	*corrected average A-weighted normal sound intensity level* $\overline{L_{\text{IA}}} = \overline{L_{\text{IA0}}}$ *if* $\Delta L \leq 4$ *dB* $\overline{L_{\text{IA}}} = \overline{L_{\text{pA0}}} - 4dB$ *if 4 dB* $< \Delta L \leq 8$ *dB* *If* $\Delta L > 8$ *dB, the measurement is declared invalid.*	dB(A)
S	…	*area of measurement surface (surface area)* $S = (h + x)\, l_{\text{m}}$ h *– height of principal radiating surface;* x *– measurement distance;* l_{m} *– length of prescribed contour*	m^2 m
L_{S}	…	*surface measure in dB* $L_{\text{S}} = 10 \times \lg \frac{S}{S_0}$	dB
L_{WA}	…	*A-weighted sound power level (calculated from corrected spatially averaged A-weighted normal sound intensity level* $\overline{L_{\text{IA}}}$ *)* $L_{\text{WA}} = \overline{L_{\text{IA}}} + 10 \times \lg \frac{S}{S_0}$, applies to each frequency band $\overline{L^{\nu}_{\text{WA}}}$	dB(A)
L_{sum}	…	*logarithmic addition for sound levels* $L_{\text{sum}} = 10 \times \lg\left(10^{0,1L_1} + 10^{0,1L_2} + \ldots + 10^{0,1L_n}\right)$ *logarithmic addition for sound levels with a direction flag* $L_{\text{sum}} = 10 \times lg\left\lvert F_{\text{Dir1}} \times 10^{0,1L_1} + F_{\text{Dir2}} \times 10^{0,1L_2} + \ldots + F_{\text{Dir n}} \times 10^{0,1L_n}\right\rvert$	dB(A)
$F_{\text{Dir sum}}$	…	*direction flag of* L_{sum} $F_{\text{Dir sum}} = Sign\left(F_{\text{Dir1}} \times 10^{0,1L_1} + F_{\text{Dir2}} \times 10^{0,1L_2} + \ldots + F_{\text{Dir n}} \times 10^{0,1L_n}\right)$	

Sound intensity method **Report No.: DEF-456**

Prescribed contours

x Distance [m]	l_m Prescribed contour [m]	h Height [m]	S Surface area [m^2]	L_S Surface measure [dB]
1	30	4,6	168	22,2
2	43	6,1	348	25,4



Sound intensity method **Report No.: DEF-456**

Measurement 1

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m²]	Surface measure [dB]
			Fans	Pumps						
100			**0**		**50**	**1**	**30**	**4,6**	**168**	**22,2**

Measurement duration [s]:115

Frequency		$\overline{L_{\text{IA0}}}$		$\overline{L_{\text{pA0}}}$	$\Delta L = \overline{L_{\text{pA0}}} - \overline{L_{\text{IA0}}}$	Pressure intensity correction as per case **A** or case **B**	$\overline{L_{\text{IA}}}$	L_{WA}
[Hz]		**[dB(A)]**	$\overline{F_{\text{Dir}}}$	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**
Total sound level		**64,5**	**1**	**69,0**	**4,5**	**B**	**65,0**	**87,2**
Octave band	63							
	125							
	250							
	500							
	1 000							
	2 000							
	4 000							
	8 000							
1 / 3 Octave band	50	11,9	-1	27,1	15,2	B	0	**0**
	63	13,0	-1	25,7	12,7	B	0	**0**
	80	36,1	1	41,8	5,7	B	37,8	**60.0**
	100	55,1	1	56,4	1,3	B	52,4	**74,6**
	125	32,7	1	39,5	6,8	B	35,5	**57,7**
	160	41,8	1	44,9	3,1	B	40,9	**63,1**
	200	56,1	1	57,1	1,0	B	53,1	**75,3**
	250	46,1	1	50,2	4,1	B	46,2	**68,4**
	315	61,7	1	66,9	5,2	B	62,9	**85,1**
	400	56,2	1	59,7	3,5	B	55,7	**77,9**
	500	51,2	1	55,6	4,4	B	51,6	**73,8**
	630	44,2	1	51,4	7,2	B	47,4	**69,6**
	800	39,1	1	45,2	6,1	B	41,2	**63,4**
	1 000	36,5	1	44,5	8,0	B	40,5	**62,7**
	1 250	37,5	1	46,2	8,7	B	42,2	**64,4**
	1 600	41,8	-1	48,0	6,2	B	0	**0**
	2 000	34,4	-1	51,1	16,7	B	0	**0**
	2 500	29,9	1	48,8	18,9	B	44,8	**67.0**
	3 150	33,3	-1	47,7	14,4	B	0	**0**
	4 000	30,7	1	46,7	16,0	B	42,7	**64,9**
	5 000	25,9	1	43,3	17,4	B	39,3	**61,5**
	6 300	26,4	1	38,6	12,2	B	34,6	**56,8**
	8 000	23,5	1	42,9	19,4	B	38,9	**61,1**
	10 000	17,5	1	33,6	16,1	B	29,6	**51,8**

$\overline{L_{\text{IA}}}$ and L_{WA} are not reported for frequency bands with $\overline{F_{\text{Dir}}}$ = -1.

Case **A:** Applies, if the total P-I index is $\Delta L \leq 4$ dB. Then it follows $\overline{L_{\text{IA}}} = \overline{L_{\text{IA0}}}$ for both the total sound level and sound levels of the individual frequency bands.

Case **B:** Applies, if the total P-I index is 4 dB $< \Delta L \leq 8$ dB. Then it follows $\overline{L_{\text{IA}}} = \overline{L_{\text{pA0}}}$ – 4dB for both the total sound level and sound levels of the individual frequency bands.

Sound intensity method **Report No.: DEF-456**

Measurement 2

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m^2]	Surface measure [dB]
			Fans	Pumps						
	100	1	0		50	1	30	4,6	168	22,2

Measurement duration [s]: 104

Frequency		$\overline{L_{IA0}}$		$\overline{L_{pA0}}$	$\Delta L = \overline{L_{pA0}} - \overline{L_{IA0}}$	Pressure intensity correction as per case **A** or case **B**	$\overline{L_{IA}}$	L_{WA}
[Hz]		**[dB(A)]**	$\overline{F_{Dir}}$	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**	**[dB(A)]**
Total sound level		**64,8**	**1**	**67,2**	**2,4**	**A**	**64,8**	**87,0**
Octave band	63							
	125							
	250							
	500							
	1 000							
	2 000							
	4 000							
	8 000							
1 / 3 Octave band	50	19,3	1	28,7	9,4	A	19,3	**41,5**
	63	51,5	1	54,2	2,7	A	51,5	**73,7**
	80	10,6	-1	25,5	14,9	A	0	**0**
	100	63,1	1	65,4	2,3	A	63,1	**85,3**
	125	40,1	1	41,8	1,7	A	40,1	**62,3**
	160	43,8	1	46,4	2,6	A	43,8	**66,0**
	200	58,0	1	60,1	2,1	A	58,0	**80,2**
	250	44,7	1	48,1	3,4	A	44,7	**66,9**
	315	49,6	1	52,2	2,6	A	49,6	**71,8**
	400	44,1	1	48,9	4,8	A	44,1	**66,3**
	500	42,2	1	46,5	4,3	A	42,2	**64,4**
	630	35,4	1	43,1	7,7	A	35,4	**57,6**
	800	31,2	1	40,8	9,6	A	31,2	**53,4**
	1 000	31,3	1	42,1	10,8	A	31,3	**53,5**
	1 250	28,3	1	40,5	12,2	A	28,3	**50,5**
	1 600	25,6	-1	39,7	14,1	A	0	**0**
	2 000	27,7	-1	38,5	10,8	A	0	**0**
	2 500	22,6	1	39,8	17,2	A	22,6	**44,8**
	3 150	24,2	1	41,4	17,2	A	24,2	**46,4**
	4 000	17,8	1	37,6	19,8	A	17,8	**40,0**
	5 000	20,0	1	38,1	18,1	A	20,0	**42,2**
	6 300	16,9	1	40,1	23,2	A	16,9	**39,1**
	8 000	14,4	1	36,2	21,8	A	14,4	**36,6**
	10 000	13,4	1	35,6	22,2	A	13,4	**35,6**

$\overline{L_{IA}}$ and L_{WA} are not reported for frequency bands with $\overline{F_{Dir}}$ = -1.

Case **A:** Applies, if the total P-I index is $\Delta L \leq$ 4 dB. Then it follows $\overline{L_{IA}}$ = $\overline{L_{IA0}}$ for both the total sound level and sound levels of the individual frequency bands.

Case **B:** Applies, if the total P-I index is 4 dB $< \Delta L \leq$ 8 dB. Then it follows $\overline{L_{IA}}$ = $\overline{L_{pA0}}$ – 4dB for both the total sound level and sound levels of the individual frequency bands.

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Measurement 3

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m²]	Surface measure [dB]
			Fans	Pumps						
			24		50	2	43	6,1	348	25,4

Measurement duration [s]: 149

Frequency		$\overline{L_{\text{IA0}}}$		$\overline{L_{\text{pA0}}}$	$\Delta L = \overline{L_{\text{pA0}}} - \overline{L_{\text{IA0}}}$	Pressure intensity correction as per case **A** or case **B**	$\overline{L_{\text{IA}}}$	L_{WA}
[Hz]		[dB(A)]	$\overline{F_{\text{Dir}}}$	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]
Total sound level		**59,6**	**1**	**63,0**	**3,4**	**A**	**59,6**	**85,0**
Octave band	63							
	125							
	250							
	500							
	1 000							
	2 000							
	4 000							
	8 000							
1 / 3 Octave band	50	16,3	1	28,8	12,5	A	16,3	**41,7**
	63	26,4	1	34,1	7,7	A	26,4	**51,8**
	80	36,2	1	40,5	4,3	A	36,2	**61,6**
	100	37,6	1	43,3	5,7	A	37,6	**63,0**
	125	39,4	1	42,8	3,4	A	39,4	**64,8**
	160	40,7	1	43,4	2,7	A	40,7	**66,1**
	200	46,5	1	49,2	2,7	A	46,5	**71,9**
	250	47,9	1	50,7	2,8	A	47,9	**73,3**
	315	50,3	1	53,5	3,2	A	50,3	**75,7**
	400	49,9	1	52,7	2,8	A	49,9	**75,3**
	500	49,4	1	52,6	3,2	A	49,4	**74,8**
	630	49,3	1	52,8	3,5	A	49,3	**74,7**
	800	48,8	1	52,3	3,5	A	48,8	**74,2**
	1 000	47,9	1	51,5	3,6	A	47,9	**73,3**
	1 250	48,3	1	51,9	3,6	A	48,3	**73,7**
	1 600	47,2	1	51,0	3,8	A	47,2	**72,6**
	2 000	47,1	1	50,7	3,6	A	47,1	**72,5**
	2 500	45,4	1	48,8	3,4	A	45,4	**70,8**
	3 150	44,1	1	47,9	3,8	A	44,1	**69,5**
	4 000	40,7	1	44,2	3,5	A	40,7	**66,1**
	5 000	36,5	1	41,8	5,3	A	36,5	**61,9**
	6 300	32,0	1	41,2	9,2	A	32,0	**57,4**
	8 000	26,1	1	36,6	10,5	A	26,1	**51,5**
	10 000	29,0	1	38,4	9,4	A	29,0	**54,4**

$\overline{L_{\text{IA}}}$ and L_{WA} are not reported for frequency bands with $\overline{F_{\text{Dir}}}$ = -1.

Case **A:** Applies, if the total P-I index is $\Delta L \leq 4$ dB. Then it follows $\overline{L_{\text{IA}}} = \overline{L_{\text{IA0}}}$ for both the total sound level and sound levels of the individual frequency bands.

Case **B:** Applies, if the total P-I index is 4 dB $< \Delta L \leq 8$ dB. Then it follows $\overline{L_{\text{IA}}} = \overline{L_{\text{pA0}}}$ – 4dB for both the total sound level and sound levels of the individual frequency bands.

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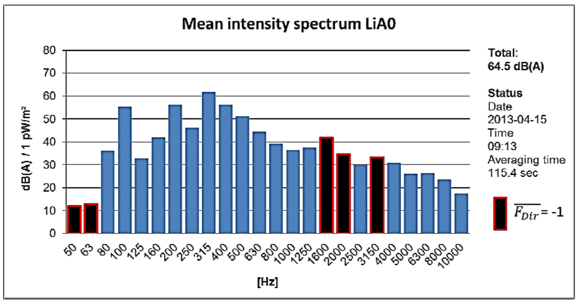
Measurement graphs

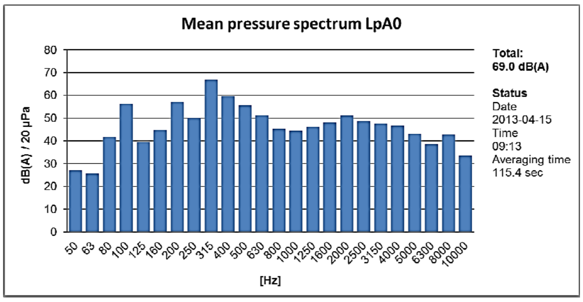
Measurement 1

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m²]	Surface measure [dB]
			Fans	Pumps						
100			0		50	1	30	4,6	168	22,2

$\overline{L_{\text{IA0}}}$



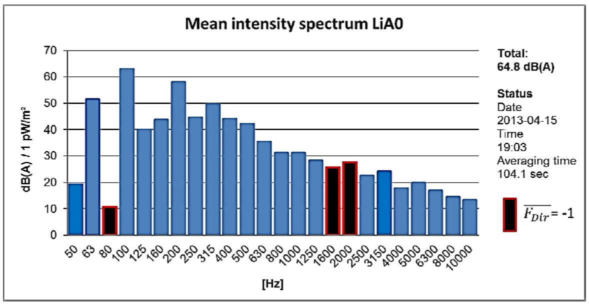
$\overline{L_{\text{pA0}}}$



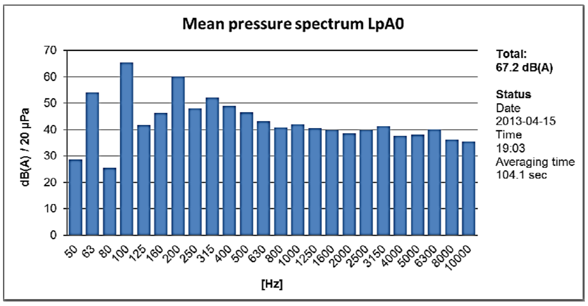
Measurement 2

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m²]	Surface measure [dB]
			Fans	Pumps						
	100	1	0		50	1	30	4,6	168	22,2

$\overline{L_{\text{IA0}}}$



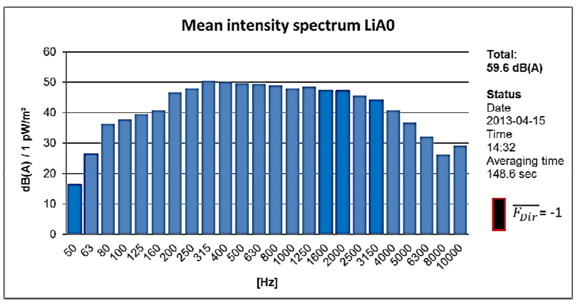
$\overline{L_{\text{pA0}}}$



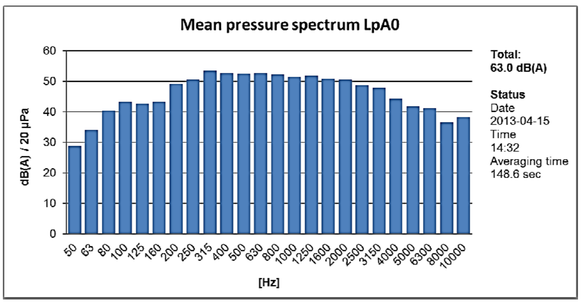
Measurement 3

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m²]	Surface measure [dB]
			Fans	Pumps						
			24		50	2	43	6,1	348	25,4

$\overline{L_{\text{IA0}}}$



$\overline{L_{\text{pA0}}}$



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B.4 Sound intensity method – Appendix for the point-by-point procedure

Sound intensity method **Report No.: DEF-456**

Measurement 1

Rated voltage [%]	Rated current [%]	Tap position	In operation		Excitation frequency [Hz]	Distance [m]	Prescribed contour [m]	Height [m]	Surface area [m²]	Surface measure [dB]
			Fans	Pumps						
100			0		50	1	30	4,6	168	22,2

Average measurement duration per point [sec.]: 3

Path at 1/3 of test object height, Points 01-05 of 30

		Path 1/3 **Point 01** / 30			Path 1/3 **Point 02** / 30			Path 1/3 **Point 03** / 30			Path 1/3 **Point 04** / 30			Path 1/3 **Point 05** / 30		
Frequency		L_{IAi}		L_{pAi}	L_{IAi}		L_{pAi}	L_{IAi}		L_{pAi}	L_{IAi}		L_{pAi}	L_{IAi}		L_{pAi}
[Hz]		[dB(A)]	F_{Dir}	[dB(A)]	[dB(A)]	F_{Dir}	[dB(A)]	[dB(A)]	F_{Dir}	[dB(A)]	[dB(A)]	F_{Dir}	[dB(A)]	[dB(A)]	F_{Dir}	[dB(A)]
Total sound level																
Octave band	63															
	125															
	250															
	500															
	1 000															
	2 000															
	4 000															
	8 000															
1 / 3 Octave band	50															
	63															
	80															
	100															
	125															
	160															
	200															
	250															
	315															
	400															
	500															
	630															
	800															
	1 000															
	1 250															
	1 600															
	2 000															
	2 500															
	3 150															
	4 000															
	5 000															
	6 300															
	8 000															
	10 000															

Bibliography

IEC 60076-6, *Power transformers – Part 6: Reactors*

IEC 60076-11, *Power transformers – Part 11: Dry-type transformers*

IEC 60076-10-1:2016, *Power transformers – Part 10-1: Determination of sound levels – Application guide*

IEC 61378 (all parts), *Convertor transformers*

(*Continued from second cover*)

In this standard, reference appears to International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60076-8 : 1997 Power transformers — Part 8: Application guide	IS 2026 (Part 8) : 2009 Power transformers: Part 8 Application guide	Identical
IEC 61672-1 Electroacoustics — Sound level meters — Part 1: Specifications	IS 15575 (Part 1) 2016/IEC 61672-1 : 2013 Electroacoustics — Sound level meters: Part 1 Specifications (*first revision*)	Identical
IEC 61672-2 Electroacoustics — Sound level meters — Part 2: Pattern evaluation tests	IS 15575 (Part 2) : 2023/IEC 61672-2 : 2013 Electroacoustics — Sound level meters: Part 2 Pattern evaluation tests (*second revision*)	Identical

The Committee has reviewed the provisions of the following international standards referred in this adopted standard and decided that they are acceptable for use in conjunction with this standard:

International Standard	*Title*
ISO 3382-2 : 2008	Acoustics — Measurement of room acoustic parammeters — Part 2: Reverberation time in ordinary rooms
ISO 3746 : 2010	Acoustics — Determination of sound power levels and sound energy levels of noises sources causing sound pressure — Survey method using an enveloping measurement surface over a reflecting plane
ISO 9614-1 : 1993	Acoustics — Determination of sound power levels of noise sources using sound intensity — Part 1: Measurement at discrete points
ISO 9614-2 : 1996	Acoustics — Determination of sound power levels of noise sources using sound intensity — Part 2: Measurement by scanning
IEC 60076-1 : 2011	Power transformers — Part 1: General
IEC 61043 : 1993	Electroacoustics — Instruments for the measurement of sound intensity — Measurements with pairs of pressure sensing microphones

Only the English language text has been retained while adopting it in this Indian Standard, and as such, the page numbers given here are not the same as in the IEC Publication.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated expressing the result to a test, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding of numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Amendments Issued Since Publication

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