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Transformateurs de puissance –

Partie 10: Détermination des niveaux de bruit

Power transformers –

Part 10: Determination of sound levels

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International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 10: Determination of sound levels

FOREWORD

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International Standard IEC 60076-10 has been prepared by IEC technical committee 14: Power transformers.

This first edition of IEC 60076-10 cancels and replaces IEC 60551, published in 1987 and its amendment 1 (1995), and constitutes a technical revision.

This bilingual version (2005-07) replaces the English version.

The text of this standard is based on the following documents:

FDIS	Report on voting
14/390/FDIS	14/394/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

The French version of this standard has not been voted upon.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

IEC 60076 consists of the following parts, under the general title *Power transformers:*

Part 1: General

Part 2: Temperature rise

Part 3: Insulation levels, dielectric tests and external clearances in air

Part 4: Guide to the lightning impulse and switching impulse testing – Power transformers and reactors

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: Determination of sound levels

Part 11: Dry-type transformers

Part 13: Self protected liquid filled transformers

Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

INTRODUCTION

One of the many parameters to be considered when designing and siting transformers, reactors and their associated cooling equipment is the amount of sound that the equipment is likely to emit under normal operating conditions on site.

Sources of sound

The audible sound radiated by transformers is generated by a combination of magnetostrictive deformation of the core and electromagnetic forces in the windings, tank walls and magnetic shields. Historically, the sound generated by the magnetic field inducing longitudinal vibrations in the core laminations has been dominant. The amplitude of these vibrations depends on the flux density in the laminations and the magnetic properties of the core steel, and is therefore independent of the load current. Recent advances in core design, combined with the use of low induction levels, have reduced the amount of sound generated in the core such that the sound caused by the electromagnetic forces may become significant.

Current flowing in the winding conductors produces electromagnetic forces in the windings. In addition, stray magnetic fields may induce vibrations in structural components. The force (and therefore the amplitude of the vibrations) is proportional to the square of the current, and the radiated sound power is proportional to the square of the vibrational amplitude. Consequently, the radiated sound power is strongly dependent on the load current. Vibrations in core and winding assemblies can then induce sympathetic vibrations in tank walls, magnetic shields and air ducts (if present).

In the case of dry-type, air-cored shunt or series reactors, sound is generated by electromagnetic forces acting on the windings in a similar manner to that described above. These oscillatory forces cause the reactor to vibrate both axially and radially, and the axial and radial supports and manufacturing tolerances may result in the excitation of modes in addition to those of rotational symmetry. In the case of iron-cored reactors, further vibrations are induced by forces acting in the magnetic circuit.

For all electrical plants, the consequence of the presence of higher harmonics on the power supply should be understood. Normally, vibrations occur at even harmonics of the power frequency, with the first harmonic being dominant. If other frequencies are present in the power supply, other forces may be induced. For certain applications, this may be significant, particularly because the human ear is more sensitive to these higher frequencies.

Any associated cooling equipment will also generate noise when operating. Fans and pumps both tend to generate broad-band noise due to the forced flow of air or oil.

Measurement of sound

Sound level measurements have been developed to quantify pressure variations in air that a human ear can detect. The smallest pressure variation that a healthy human ear can detect is 20 μPa. This is the reference level (0 dB) to which all the other levels are compared. The perceived loudness of a signal is dependent upon the sensitivity of the human ear to its frequency spectrum. Modern measuring instruments process sound signals through electronic networks, the sensitivity of which varies with frequency in a manner similar to the human ear. This has resulted in a number of internationally standardized weightings of which the A-weighting network is the most common.

Sound intensity is defined as the rate of energy flow per unit area and is measured in watts per square metre. It is a vector quantity whereas, sound pressure is a scalar quantity and is defined only by its magnitude.

Sound power is the parameter which is used for rating and comparing sound sources. It is a basic descriptor of a source's acoustic output, and therefore an absolute physical property of the source alone which is independent of any external factors such as environment and distance to the receiver.

Sound power can be calculated from sound pressure or sound intensity determinations. Sound intensity measurements have the following advantages over sound pressure measurements:

- an intensity meter responds only to the propagating part of a sound field and ignores any non-propagating part, for example, standing waves and reflections;
- the intensity method reduces the influence of external sound sources, as long as their sound level is approximately constant.

The sound pressure method takes the above factors into account by correcting for background noise and reflections.

For a detailed discussion of these measuring techniques, see IEC 60076-10-1: Determination of sound levels – Application guide.

POWER TRANSFORMERS –

Part 10: Determination of sound levels

1 Scope

This part of IEC 60076 defines sound pressure and sound intensity measurement methods by which sound power levels of transformers, reactors and their associated cooling auxiliaries may be determined.

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

The methods are applicable to transformers and reactors covered by the IEC 60076 series, IEC 60289, IEC 60076-11 and the IEC 61378 series, without limitation as regards size or voltage and when fitted with their normal cooling auxiliaries.

This standard is primarily intended to apply to measurements made at the factory. Conditions on-site may be very different because of the proximity of objects, including other transformers. Nevertheless, the same general rules as are given in this standard may be followed when on-site measurements are made.

2 Normative references

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

IEC 60076 (all parts), *Power transformers*

IEC 60076-1:1993, *Power transformers – Part 1: General*

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

IEC 60289:1988, *Reactors*

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

IEC 61378 (all parts), *Convertor transformers*

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

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

ISO 3746:1995, *Acoustics – Determination of sound power 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*

3 Terms and definitions

For the purpose of this document, the definitions in IEC 60076-1, as well as the following definitions, apply.

3.1
sound pressure

p

fluctuating pressure superimposed on the static pressure by the presence of sound. It is expressed in pascals

3.2
sound pressure level

L_p

ten times the logarithm to the base 10 of the ratio of the square of the sound pressure to the square of the reference sound pressure (p_0 = 20 × 10^{-6} Pa). It is measured in decibels

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

3.3
sound intensity

I

vector quantity describing the amount and direction of the net flow of sound energy at a given position. The unit is Wm^{-2}

3.4
normal sound intensity

I_n

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

3.5
normal sound intensity level

L_I

ten times the logarithm to the base 10 of the ratio of the normal sound intensity to the reference sound intensity (I_0 = 1 × 10^{-12} Wm^{-2}). It is expressed in decibels

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

NOTE When I_n is negative, the level is expressed as –XX dB.

3.6
sound power

W

rate at which airborne sound energy is radiated by a source. It is expressed in watts

3.7
sound power level

L_W

ten times the logarithm to the base 10 of the ratio of a given sound power to the reference sound power (W_0 = 1 × 10^{-12} W). It is expressed in decibels

$$L_W = 10 \lg \frac{W}{W_0} \qquad (3)$$

3.8
principal radiating surface
hypothetical surface surrounding the test object which is assumed to be the surface from which sound is radiated

3.9
prescribed contour
horizontal line on which the measuring positions are located, spaced at a definite horizontal distance (the "measurement distance") from the principal radiating surface

3.10
measurement distance
X
horizontal distance between the principal radiating surface and the "measurement surface"

3.11
measurement surface
hypothetical surface enveloping the source and on which the measurement points are located

3.12
background noise
A-weighted sound pressure level with the test object inoperative

4 Instrumentation and calibration

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.

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. 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 measuring equipment shall be calibrated 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.

5 Choice of test method

Either sound pressure or sound intensity measurements may be used to determine the value of the sound power level. Both methods are valid and either can be used, as agreed between manufacturer and purchaser at the time of placing the order.

The sound pressure method of measurement described in this standard is in accordance with 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.

The sound intensity method of measurement described in this standard is in accordance with ISO 9614-1. 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.

6 Load conditions

6.1 General

Load condition(s) shall be agreed between the manufacturer and purchaser at the time of placing the order. If a transformer has a very low no-load sound level, the sound due to load current can influence the total sound level in service. The method to be used for summing the no-load and load current sound levels is given in Clause 14.

Current taken by a reactor is dependent on the voltage applied and consequently, a reactor cannot be tested at no-load. Where sufficient power is available in the factory to permit full energization of reactors, the methods to be followed are the same as those for transformers. Alternatively, measurements may be made on-site if conditions are suitable.

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. In addition, when the transformer is in service, a superposition of the flux at no-load conditions and the stray flux occurs which causes a change in the flux density in certain parts of the core. Therefore, under special conditions of intended application of a transformer (particularly variable flux voltage variation), it may be agreed to measure the sound levels on a tapping other than the principal tapping, or with a voltage other than the rated voltage on an untapped winding. This shall be clearly indicated in the test report.

6.2 No-load current and rated voltage

For measurements made on the test object with or without its auxiliary cooling plant, the test object shall be on no-load and excited at the rated voltage of sinusoidal or practically sinusoidal waveform and rated frequency. The voltage shall be in accordance with 10.5 of IEC 60076-1. If a transformer is fitted with reactor-type on-load tap-changer equipment where the reactor may on certain tap-change positions be permanently energized, the measurements shall be made with the transformer on a tapping which involves this condition and which is as near to the principal tapping as possible. The excitation voltage shall be appropriate to the tapping in use. This shall be clearly indicated in the test report.

NOTE DC bias currents may cause a significant increase in the measured sound levels. Their presence may be verified by the existence of odd harmonics of the power frequency in the sound spectrum. The implications of increased sound levels due to d.c. bias currents should be taken into consideration by both the manufacturer and purchaser.

For North American applications, the sound level tests shall be made at no-load in accordance with national requirements.

6.3 Rated current and short-circuit voltage

In order to decide whether it is significant to perform load current sound measurements, the magnitude of the load current sound power level can be roughly estimated by equation (4):

$$L_{\mathrm{WA,IN}} \approx 39 + 18 \lg \frac{S_\mathrm{r}}{S_\mathrm{p}} \qquad (4)$$

where

$L_{\mathrm{WA,IN}}$ is the A-weighted sound power level of the transformer at rated current, rated frequency and impedance voltage;

S_r is the rated power in megavolt amperes (MVA);

S_p is the reference power (1 MVA).

For auto-transformers and three winding transformers, the two winding rated power, S_t, is used instead of S_r.

If $L_{WA,IN}$ is found to be 8 dB or more below the guaranteed sound power level, load current sound measurements are not appropriate.

When these measurements are required, one winding shall be short-circuited and a sinusoidal voltage as defined in 10.5 of IEC 60076-1 applied to the other winding at the rated frequency. The voltage shall be gradually increased until rated current flows in the short-circuited winding.

6.4 Reduced-load current

If the measurements can only be performed at a reduced current, the sound power level at the rated current shall be calculated by equation (5):

$$L_{WA,IN} = L_{WA,IT} + 40 \lg \frac{I_N}{I_T} \qquad (5)$$

where

$L_{WA,IN}$ is the A-weighted sound power level at rated current;

$L_{WA,IT}$ is the A-weighted sound power level at reduced current;

I_N is the rated current;

I_T is the reduced current.

The equation is valid for a reduced current of ≥70 % of the rated current.

7 Principal radiating surface

7.1 General

The definition of the principal radiating surface depends on the type of cooling auxiliaries employed and their position relative to the transformer. For the purpose of this standard, "cooling auxiliaries" shall include forced air and forced oil cooling auxiliaries and water cooling equipment, and shall exclude natural air and natural oil cooling.

7.2 Transformers with or without cooling auxiliaries, dry-type transformers in enclosures and dry-type transformers with cooling auxiliaries 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 transformer tank cover (excluding bushings, turrets and other accessories situated above the tank cover) to the base of the tank. The principal radiating surface shall include cooling auxiliaries located <3 m away from the transformer tank, tank stiffeners and such auxiliary equipment as cable boxes, tap-changers, etc. It shall exclude any cooling auxiliaries located ≥3 m away from the transformer tank. Projections such as bushings, oil pipework and conservators, tank or cooler underbases, valves, control cubicles and other secondary elements shall also be excluded, (see Figures 1, 2 and 3).

7.3 Cooling auxiliaries mounted on a separate structure spaced ≥3 m away from the principal radiating surface of the transformer

The principal radiating surface is the surface obtained by the vertical projection of a string contour encircling the equipment but excluding oil conservators, framework, pipework, valves and other secondary elements. The vertical projection shall be from the top of the cooler structure to the base of the active parts (see Figure 4).

7.4 Dry-type transformers without enclosures

The principal radiating surface is the surface obtained by the vertical projection of a string contour encircling the dry-type transformer excluding 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 base of the active part (see Figure 5).

8 Prescribed contour

For measurements made with forced air cooling auxiliaries (if any) out of service, the prescribed contour shall be spaced 0,3 m away from the principal radiating surface unless, for safety reasons associated with dry-type units without enclosures, 1 m is chosen.

For measurements made with forced air cooling auxiliaries in service, the prescribed contour shall be spaced 2 m away from the principal radiating surface.

For transformers with a tank height of <2,5 m, the prescribed contour shall be on a horizontal plane at half the tank height. For transformers with a tank height ≥2,5 m, two prescribed contours shall be used which are on horizontal planes at one-third and two-thirds of the tank height unless, for safety reasons, a lower height is chosen.

For measurements made with the cooling auxiliaries only energized, the prescribed contour for cooler structures with an overall height of <4 m (excluding oil conservators, pipework, etc.) shall be on a horizontal plane at half the height. For cooler structures with an overall height of ≥4 m (excluding oil conservators, pipework, etc.), two prescribed contours shall be used which are on horizontal planes at one-third and two-thirds of the height, unless for safety reasons, a lower height is chosen.

NOTE It may be necessary to modify the measuring positions for certain test objects on safety grounds, for example, in the case of transformers with horizontal high voltage bushings, the contour(s) may be confined to the safe zone.

9 Microphone positions

The microphone positions shall be on the prescribed contour(s), approximately equally spaced and not more than 1 m apart, (see dimension D in Figures 1 to 5). There shall be a minimum of six microphone positions.

Storage-type measuring equipment with an averaging device may be used. The microphone shall be moved with approximately constant speed on the prescribed contour(s) around the test object. The number of samples shall be not less than the number of microphone positions specified above. Only the energy average shall be recorded in the test report

10 Calculation of the area of the measurement surface

10.1 Measurements made at 0,3 m from the principal radiating surface

The area S of the measurement surface, expressed in square metres, is given by equation (6):

$$S = 1{,}25\ h l_m \tag{6}$$

where

h is either the height in metres of the transformer tank (Figures 1, 2 or 3) or, for dry-type transformers without enclosures (Figure 5), the height in metres of the core and its framework;

l_m is the length in metres of the prescribed contour;

1,25 is an empirical factor intended to take account of the sound energy radiated by the upper part of the test object.

10.2 Measurements made at 2 m from the principal radiating surface

The area S of the measurement surface, expressed in square metres, is given by equation (7):

$$S = (h + 2)\ l_m \tag{7}$$

where

h is either the height in metres of the transformer tank (Figure 2 or 3), or the height in metres of the cooling auxiliaries including fans (Figure 4);

l_m is the length in metres of the prescribed contour;

2 is the measurement distance in metres.

10.3 Measurements made at 1 m from the principal radiating surface

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

$$S = (h + 1)\ l_m \tag{8}$$

where

h is the height in metres of the core with framework (Figure 5);

l_m is the length in metres of the prescribed contour;

1 is the measurement distance in metres.

10.4 Measurements on test objects where safety clearance considerations require a measurement distance which for all or part of the prescribed contour(s) exceeds the provisions of 10.1 to 10.3

The area S of the measurement surface, expressed in square metres, is calculated by equation (9):

$$S = \frac{3}{4\pi} l_m^2 \tag{9}$$

where l_m is the length in metres of the prescribed contour as dictated by safety clearances.

11 Sound pressure method

11.1 Test environment

11.1.1 General

An environment providing an approximately free field over a reflecting plane shall be used. The test environment shall ideally provide a measurement surface which lies inside a sound field essentially undisturbed by reflections from nearby objects and the environment boundaries. Therefore, reflecting objects (with the exception of the supporting surface) shall be removed as far as possible from the test object.

Measurements inside transformer cells or enclosures are not allowed.

For indoor measurements, the requirements of 11.1.2 shall be met. For outdoor measurements in a test area, the requirements of 11.1.3 shall be met.

11.1.2 Conditions for indoor measurements

11.1.2.1 Reflecting planes

The reflecting plane is usually the floor of the room and shall be larger than the projection of the measurement surface upon it.

NOTE Care should be taken to ensure that the supporting surface does not radiate an appreciable sound energy due to vibration.

The acoustic absorption coefficient shall preferably be less than 0,1 over the frequency range concerned. This requirement is usually fulfilled when indoor measurements are made over concrete, resin, steel or hard tile flooring.

11.1.2.2 Calculation of environmental correction K

The environmental correction K accounts for the influence of undesired sound reflections from room boundaries and/or reflecting objects near the test object. 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 calculated magnitude of K does not depend strongly on the location of the test object in the test room.

K shall be obtained from equation (10) or Figure 6 by entering the abscissa with the appropriate value of A/S.

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

The value of S shall be calculated from the appropriate equation (equation (6), (7), (8) or (9)). The value of A in square metres is given by equation (11):

$$A = \alpha S_{\mathrm{v}} \tag{11}$$

where

α is the average acoustic absorption coefficient (see Table 1);

S_{v} is the total area of the surface of the test room (walls, ceilings and floors) in square metres.

Table 1 – Approximate values of the average acoustic absorption coefficient

Description of room	Average acoustic absorption coefficient, α
Nearly empty room with smooth hard walls made of concrete, brick, plaster or tile	0,05
Partly empty room with smooth walls	0,1
Room with furniture, rectangular machinery room, rectangular industrial room	0,15
Irregularly shaped room with furniture, irregularly shaped machinery room or industrial room	0,2
Room with upholstered furniture, machinery or industrial room with a small amount of acoustic material (for example partially absorptive ceiling) on ceiling or walls	0,25
Room with acoustic materials on both ceilings and walls	0,35
Room with large amounts of acoustic material on ceilings and walls	0,5

If a measured value of the sound absorption area A is desired, it may be determined by measuring the reverberation time of the test room which is excited by broad-band sound or an impulsive sound with A-weighting on the receiving system. The value of A is given in square metres by equation (12):

$$A = 0{,}16\ (V/T) \quad (12)$$

where

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

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

For a test room to be satisfactory, A/S shall be ≥1. This will give a value for the environmental correction factor K ≤7 dB.

For very large rooms. and work spaces which are not totally enclosed, the value of K approaches 0 dB.

11.1.2.3 Alternative method for calculation of environmental correction *K*

K may be calculated by determining the apparent sound power level of a reference sound source which has previously been calibrated in a free field over a reflecting plane. In this case:

$$K = L_{\mathrm{Wm}} - L_{\mathrm{Wr}} \quad (13)$$

where

L_{Wm} is the sound power level of the reference sound source, determined according to Clauses 7 and 8 of ISO 3746 without the environmental correction K, that is, it is initially assumed that K = 0;

L_{Wr} is the apparent sound power level of the reference sound source.

11.1.3 Conditions for outdoor measurements

11.1.3.1 Reflecting planes

The reflecting plane shall be either undisturbed earth or an artificial surface such as concrete or sealed asphalt and shall be larger than the projection of the measurement surface upon it.

The acoustic absorption coefficient shall preferably be less than 0,1 over the frequency range of interest. This requirement is usually fulfilled when outdoor measurements are made over concrete, sealed asphalt, sand or stone surfaces.

11.1.3.2 Environmental correction K

For measurements outdoors in a sound field which is essentially undisturbed by reflections from nearby objects and the environment boundaries, K is approximately equal to zero. If the sound field is affected by reflections, K shall be determined according to the method described in 11.1.2.3 or the sound intensity method shall be used.

11.1.3.3 Precautions for outdoor measurements

Measurements shall not be made under extreme meteorological conditions, for example, in the presence of temperature gradients, wind gradients, precipitation or high humidity.

11.2 Sound pressure level measurements

The measurements shall be taken when the background noise is approximately constant.

The A-weighted sound pressure level of the background noise shall be measured immediately before the measurements on the test object. The height(s) of the microphone(s) during the background noise measurements shall be the same as for the measurements of the test object sound levels; the background noise measurements shall be taken at points on the prescribed contour(s).

NOTE 1 When the total 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.

NOTE 2 If the background noise pressure level is clearly much lower than the combined sound pressure level of the background noise and the test object (that is, if the difference is more than 10 dB), measurements of the background noise may be made at only one of the measuring positions and no correction of the measured sound level of the equipment is necessary.

The test object shall be energized as agreed by the manufacturer and purchaser. The permissible combinations are as follows:

a) transformer energized, cooling equipment and any oil-circulating pumps out of service;
b) transformer energized, cooling equipment and any oil-circulating pumps in service;
c) transformer energized, cooling equipment out of service, oil-circulating pumps in service;
d) transformer unenergized, cooling equipment and any oil-circulating pumps in service.

For North American applications, sound levels shall be measured with and without the cooling equipment in operation.

The A-weighted sound pressure level shall be recorded for each measuring position. The fast response indication of the meter shall be used to identify and avoid measurement errors due to transient background noise.

NOTE 3 When the test object is energized, it is advisable to delay sound measurements until a stable condition is attained. If residual d.c. is present, the sound level may be affected for a few minutes or, in extreme cases, for several hours. Residual d.c. is indicated by the presence of odd harmonics in the sound spectrum. Once stability has been reached, it is recommended that the time spent making measurements be minimized to avoid changes in the sound level caused by changes in transformer temperature.

The test object shall be de-energized and the background noise pressure level measurements repeated.

11.3 Calculation of average sound pressure level

The uncorrected average A-weighted sound pressure level, $\overline{L_{pA0}}$, shall be calculated from the A-weighted sound pressure levels, L_{pAi}, measured with the test object energized by using equation (14):

$$\overline{L_{pA0}} = 10\lg\left(\frac{1}{N}\sum_{i=1}^{N}10^{0,1L_{pAi}}\right) \tag{14}$$

where N is the total number of measuring positions.

NOTE 1 When the range of values of L_{pAi} does not exceed 5 dB, a simple arithmetical average may be used. This average will not differ by more than 0,7 dB from the value calculated using equation (14).

The average A-weighted background noise pressure level, $\overline{L_{bgA}}$, shall be calculated separately before and after the test sequence using equation (15):

$$\overline{L_{bgA}} = 10\lg\left(\frac{1}{M}\sum_{i=1}^{M}10^{0,1L_{bgAi}}\right) \tag{15}$$

where

M is the total number of measuring positions;

L_{bgAi} is the measured A-weighted background noise pressure level at the ith measuring position.

If the initial and final average background noise pressure levels differ by more than 3 dB and the higher value is less than 8 dB lower than the uncorrected average A-weighted sound pressure level, the measurements shall be declared invalid and the test repeated except in cases where the uncorrected average A-weighted sound pressure level is less than the guaranteed value. In this case, the test object shall be considered to have met the guaranteed level. This condition shall be recorded in the test report.

If the higher of the two average A-weighted background noise pressure levels is less than 3 dB lower than the uncorrected average A-weighted sound pressure level, the measurements shall be declared invalid and the test repeated except in cases where the uncorrected average A-weighted sound pressure level is less than the guaranteed value. In this case, the test object shall be considered to have met the guaranteed level. This condition shall be recorded in the test report.

NOTE 2 While the standard permits a small difference between the background noise level and the combined sound level of the background and the test object, every effort should be made to obtain a difference of at least 6 dB.

NOTE 3 When the difference between the background noise level and the combined sound level is less than 3 dB, consideration should be given to using an alternative measurement method (see Clause 12 and Annex A).

The above requirements are summarized in Table 2.

Table 2 – Test acceptance criteria

$\overline{L_{pA0}}$ – the higher $\overline{L_{bgA}}$	Initial $\overline{L_{bgA}}$ – 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 $\overline{L_{pA0}}$ is less than the guaranteed value, in which case the test object should be considered to have met the guaranteed level. This condition shall be recorded in the test report.

The corrected average A-weighted sound pressure level, $\overline{L_{pA}}$, shall be calculated by using equation (16):

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

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

For the purpose of this standard, the maximum allowable value of the environmental correction K is 7 dB (see 11.1.2.2).

NOTE 4 Transformers generate pure tones at harmonics of the power frequency. It is therefore possible that standing waves may influence the measured sound pressure levels. In this case, the application of a single correction factor does not suffice and measurements should be performed, whenever possible, in surroundings where environmental correction is not necessary.

12 Sound intensity method

12.1 Test environment

An environment providing an approximately free field over a reflecting plane shall be used. The test environment shall ideally provide a measurement surface which lies inside a sound field essentially undisturbed by reflections from nearby objects and the environment boundaries. Therefore, reflecting objects (with the exception of the supporting surface) shall be removed as far as possible from the test object. However, the sound intensity method allows accurate determinations to be made with up to two reflecting walls at least 1,2 m from the prescribed contour(s) of the test object. If there are three reflecting walls, the distance of each wall from the prescribed contour(s) shall be at least 1,8 m.

Measurements inside transformer cells or enclosures are not allowed.

NOTE In the presence of reflecting surfaces (other than the supporting surface), the test environment may be improved by the use of absorbing panels.

12.2 Sound intensity level measurements

The measurements shall be taken when the background noise is approximately constant.

The test object shall be energized as agreed by the manufacturer and purchaser. The permissible combinations are as follows:

a) transformer energized, cooling equipment and any oil-circulating pumps out of service;

b) transformer energized, cooling equipment and any oil-circulating pumps in service;

c) transformer energized, cooling equipment out of service, oil-circulating pumps in service;

d) transformer unenergized, cooling equipment and any oil-circulating pumps in service.

For North American applications, sound level shall be measured with and without the cooling equipment in operation.

The A-weighted normal sound intensity level and the A-weighted sound pressure level shall be recorded for each measuring position. The microphone spacer shall be chosen to cover the sound spectrum to be measured otherwise the lower or upper frequencies will not be taken into account and errors will be introduced. The fast response indication of the meter shall be used to identify and avoid measurement errors due to transient background noise.

NOTE 1 In practice, different microphone spacers are used for the four combinations.

NOTE 2 When the test object is energized, it is advisable to delay sound measurements until a stable condition is attained. If residual d.c. is present, the sound level may be affected for a few minutes or, in extreme cases, for several hours. Residual d.c. is indicated by the presence of odd harmonics in the sound spectrum. Once stability has been reached, it is recommended that the time spent making measurements be minimized to avoid changes in the sound level caused by changes in transformer temperature.

12.3 Calculation of average sound intensity level

The average A-weighted sound intensity level, $\overline{L_{\text{IA}}}$, shall be calculated from the A-weighted normal sound intensity levels, L_{IAi}, measured with the test object energized by using equation (17):

$$\overline{L_{\text{IA}}} = 10\lg\left(\frac{1}{N}\sum_{\text{i}=1}^{N}\text{sign}\,(L_{\text{IAi}})10^{0{,}1|L_{\text{IAi}}|}\right) \tag{17}$$

The uncorrected average A-weighted sound pressure level, $\overline{L_{\text{pA0}}}$, is calculated from the measured sound pressure levels as described in equation (14).

The criterion, ΔL, for judging the acceptability of a test environment and the background noise is given by equation (18):

$$\Delta L = \overline{L_{\text{pA0}}} - \overline{L_{\text{IA}}} \tag{18}$$

In order to maintain standard deviations which are ≤3 dB, the maximum allowable value for ΔL is 8 dB(A).

NOTE If ΔL is >8 dB(A), an alternative measurement method should be considered. See Annex A.

13 Calculation of sound power level

The A-weighted sound power level of the test object, L_{WA}, shall be calculated from either the corrected average A-weighted sound pressure level, $\overline{L_{pA}}$, or the average A-weighted sound intensity level, $\overline{L_{IA}}$, according to equation (19) or (20), respectively:

$$L_{WA} = \overline{L_{pA}} + 10\lg\frac{S}{S_0} \tag{19}$$

$$L_{WA} = \overline{L_{IA}} + 10\lg\frac{S}{S_0} \tag{20}$$

where S is derived from equation (6), (7), (8) or (9), as appropriate, and S_0 is equal to the reference area (1 m^2).

For transformers with cooling auxiliaries mounted directly on the tank, the sound power level of the cooling auxiliaries, L_{WA0}, is given by equation (21):

$$L_{WA0} = 10\lg\left(10^{0,1L_{WA1}} - 10^{0,1L_{WA2}}\right) \tag{21}$$

where

L_{WA1} is the sound power level of the transformer and cooling auxiliaries;

L_{WA2} is the sound power level of the transformer.

NOTE If the sound power levels of the individual fans and pumps of the cooling auxiliaries are known, the total sound power level of the cooling auxiliaries can be obtained by adding together the individual values on an energy basis. This method of determining the sound power level of cooling auxiliaries is subject to agreement between manufacturer and purchaser.

For transformers with cooling auxiliaries mounted on a separate structure, the sound power level of the transformer plus cooling auxiliaries, L_{WA1}, is calculated by using equation (22):

$$L_{WA1} = 10\lg\left(10^{0,1L_{WA0}} + 10^{0,1L_{WA2}}\right) \tag{22}$$

where

L_{WA2} is the sound power level of the transformer;

L_{WA0} is the sound power level of the cooling auxiliaries.

14 Addition of no-load and load current sound power levels

The A-weighted sound power level which is representative for the transformer in operation at rated voltage and rated current can be determined by summing the A-weighted no-load sound power level and the A-weighted rated current sound power level according to equation (23):

$$L_{WA,SN} = 10\lg\left(10^{0,1L_{WA,UN}} + 10^{0,1L_{WA,IN}}\right) \tag{23}$$

where

$L_{WA,SN}$ is the A-weighted sound power level of the transformer at sinusoidal rated voltage, sinusoidal rated current and rated frequency (load sound level);

$L_{WA,UN}$ is the A-weighted sound power level of the transformer at sinusoidal rated voltage, rated frequency and no load (no-load sound level) (see 6.2);

$L_{WA,IN}$ is the A-weighted rated current sound power level (see 6.3 or 6.4).

The sound of the cooling auxiliaries, if required, shall be considered by inclusion in either $L_{WA,UN}$ or $L_{WA,IN}$.

NOTE The above equation is applicable strictly only to independent sound sources. Due to the correlation of no-load and load current sound, the actual sound power level in service, $L_{WA,SN}$, will be lower than that obtained by the above equation. The differences, however, are within the measuring uncertainties.

15 Far-field calculations

As an approximate calculation, assuming free-field conditions over a reflecting plane, the A-weighted sound pressure level, L_{pAR}, at a distance R in metres from the geometrical centre of the equipment is given by equation (24):

$$L_{pAR} = L_{WA} - 10 \lg \frac{S_h}{S_0} \qquad (24)$$

where

$S_h = 2\pi R^2$ is the area of the surface of a hemisphere of radius R, and R is greater than 30 m;

L_{WA} is the A-weighted sound power level.

For a more accurate value, other factors such as atmospheric absorption, reflections and screening should be considered.

16 Presentation of results

The report shall include all the following information:

a) the name of the manufacturer and place of manufacture;

b) the date of the tests;

c) a description of the test object giving the serial number, rated power, current, voltage and frequency, voltage ratio and connections;

d) the guaranteed level and the operating and measurement conditions giving rise to this guaranteed level;

e) reference to this measurement standard;

f) the sound power level determination method used (where appropriate);

g) the characteristics of the sound measuring equipment and calibration verification (including the serial numbers of the instruments, the microphones and the calibration source);

h) a dimensioned sketch showing the position of the test object with respect to other objects in the measurement area and the measuring positions;

i) the test conditions, including the voltage, current (if appropriate), frequency, tap position and measurement distance;

j) the length of the prescribed contour(s), the height of the test object and the calculated effective surface area;

k) a list of persons present during the tests;

l) the signature of the person responsible for testing.

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

m) the A-weighted sound pressure levels of the background noise at each background noise measuring position;

n) the average A-weighted background noise pressure level before and after the measurement sequence;

o) the A-weighted sound pressure levels for each measuring position for the following test conditions (as agreed by the manufacturer and purchaser):

   1) transformer energized, cooling equipment and any oil-circulating pumps out of service;

   2) transformer energized, cooling equipment and any oil-circulating pumps in service;

   3) transformer energized, cooling equipment out of service, oil-circulating pumps in service;

   4) transformer unenergized, cooling equipment and any oil-circulating pumps in service;

p) the value of the environmental correction, K;

q) the uncorrected average A-weighted sound pressure level, $\overline{L_{\text{pA0}}}$, for each set of test conditions;

r) the corrected average A-weighted sound pressure level, $\overline{L_{\text{pA}}}$, rounded to the nearest integer, for each set of test conditions;

s) the A-weighted sound power level, L_{WA}, rounded to the nearest integer, for each set of test conditions.

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

t) the A-weighted sound intensity level for each measuring position for the following test conditions (as agreed by the manufacturer and purchaser):

   1) transformer energized, cooling equipment and any oil-circulating pumps out of service;

   2) transformer energized, cooling equipment and any oil-circulating pumps in service;

   3) transformer energized, cooling equipment out of service, oil-circulating pumps in service;

   4) transformer unenergized, cooling equipment and any oil-circulating pumps in service;

u) the A-weighted sound pressure level for each measuring position for each set of test conditions;

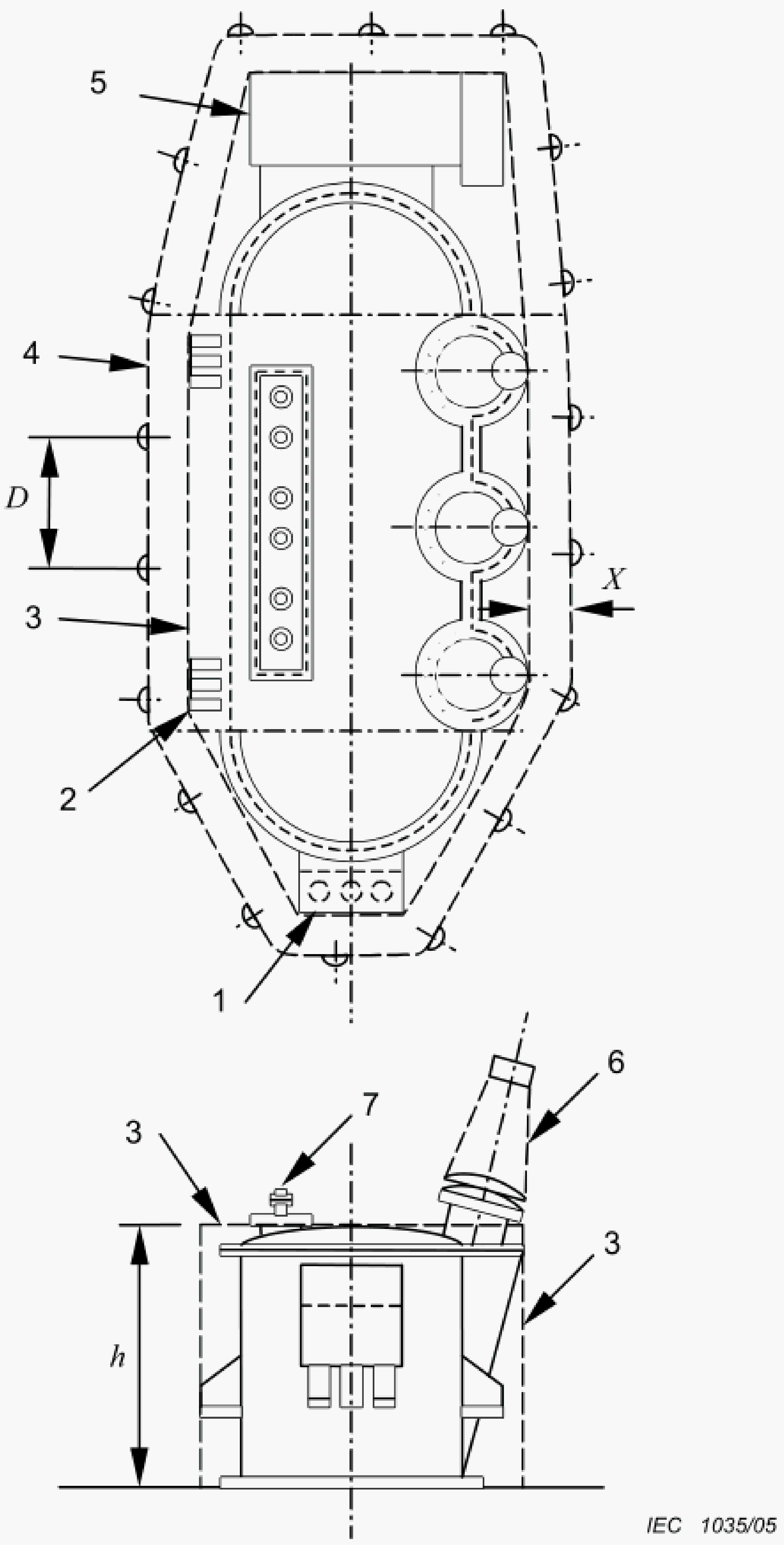
v) the uncorrected average A-weighted sound pressure level, $\overline{L_{\text{pA0}}}$, for each set of test conditions;

w) the average A-weighted sound intensity level, $\overline{L_{\text{IA}}}$, rounded to the nearest integer, for each set of test conditions;

x) the value of ΔL for each set of test conditions;

y) the A-weighted sound power level, L_{WA}, rounded to the nearest integer, for each set of test conditions.

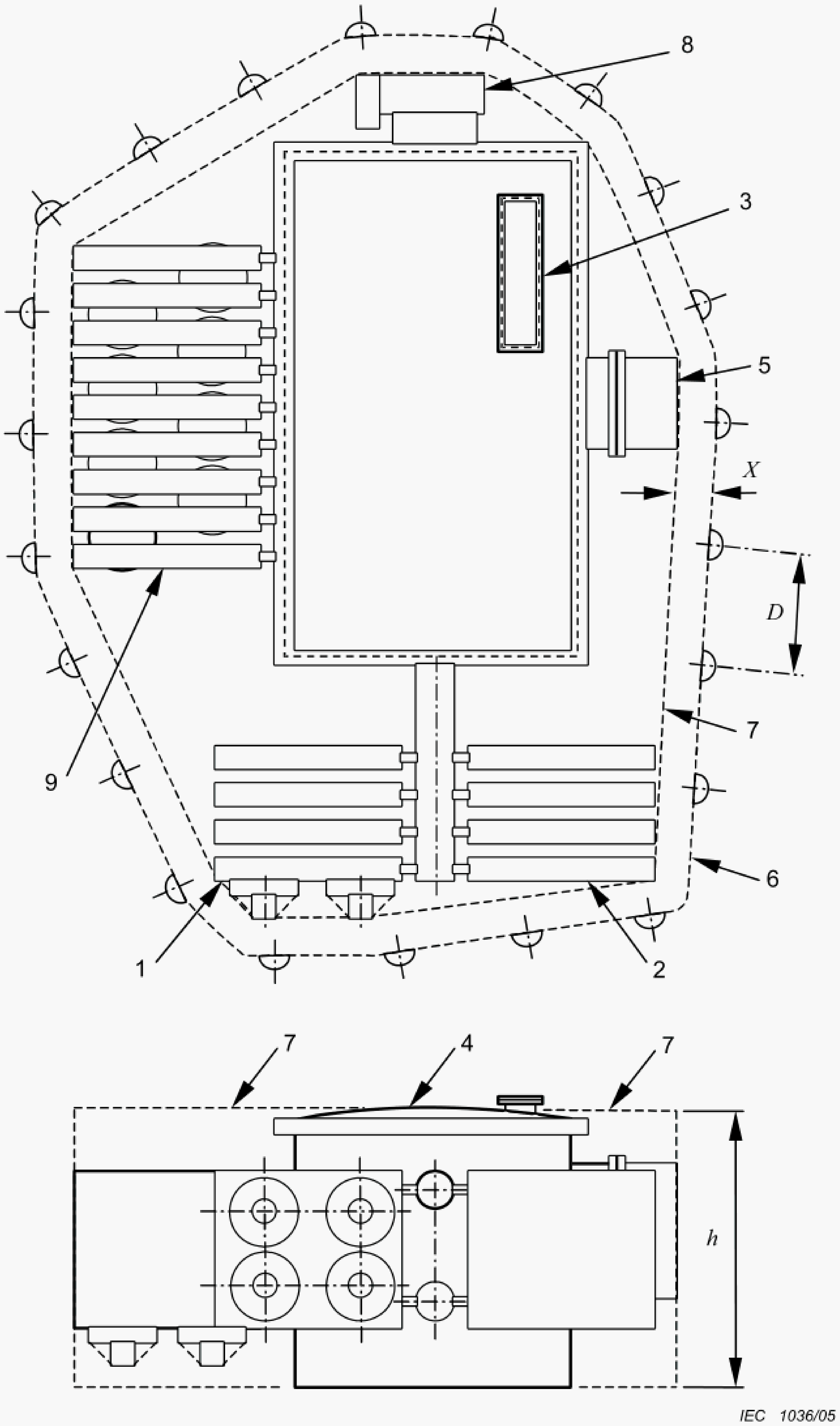
NOTE A typical form for the presentation of results is given in Annex B.



Key

1	Tertiary bushings	6	HV bushings
2	Stiffeners and jacking lug	7	LV bushings
3	Principal radiating surface	D	Microphone spacing
4	Prescribed contour	h	Height of the tank
5	On-load tap-changer	X	Measurement distance

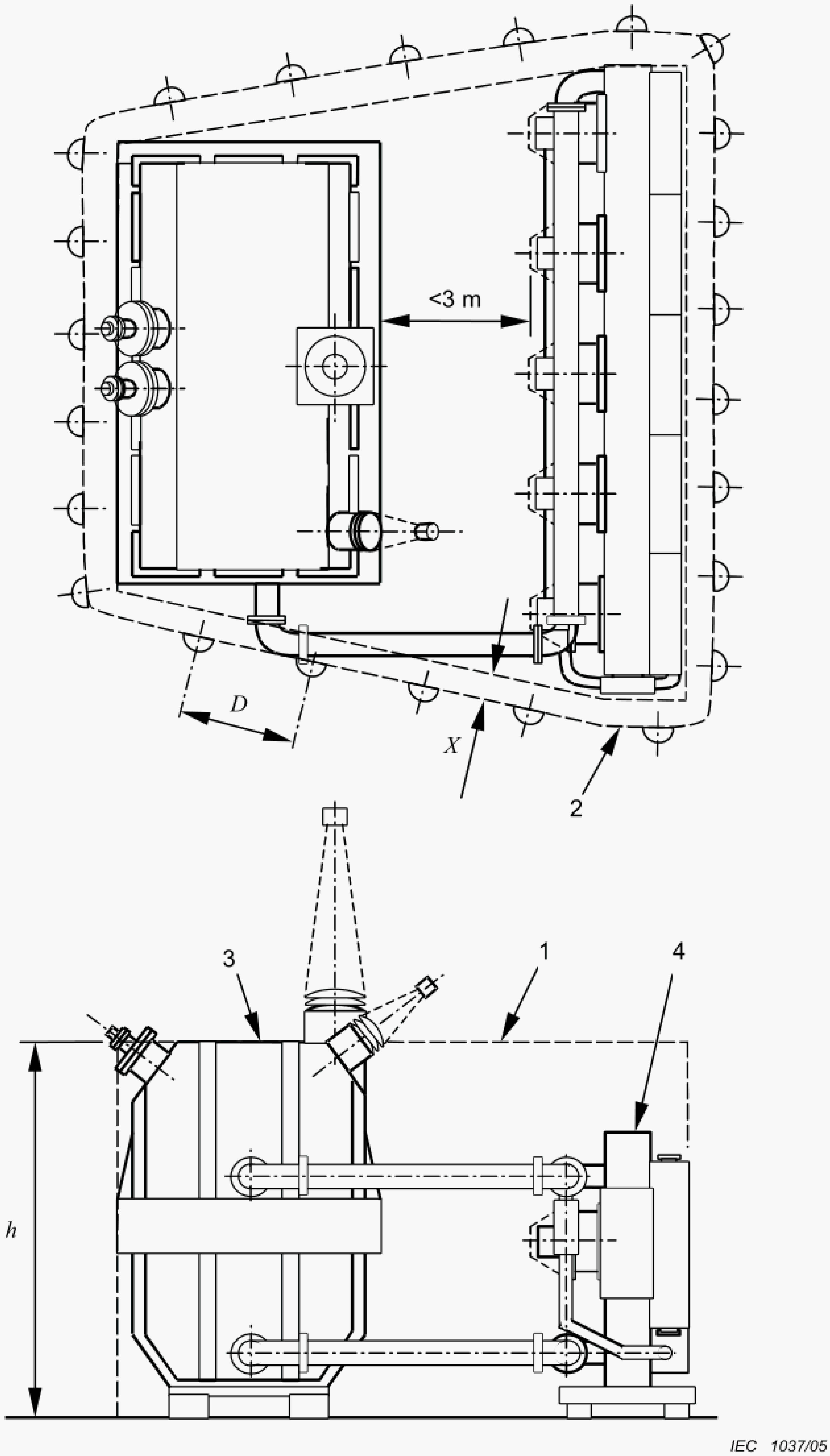
Figure 1 – Typical microphone positions for sound measurement on transformers excluding cooling equipment



Key

1 Horizontal forced air cooling
2 Natural air cooling
3 Turret
4 Transformer tank
5 Cable box
6 Prescribed contour
7 Principal radiating surface
8 On-load tap-changer
9 Vertical forced air cooling
D Microphone spacing
h Height of the tank
X Measurement distance

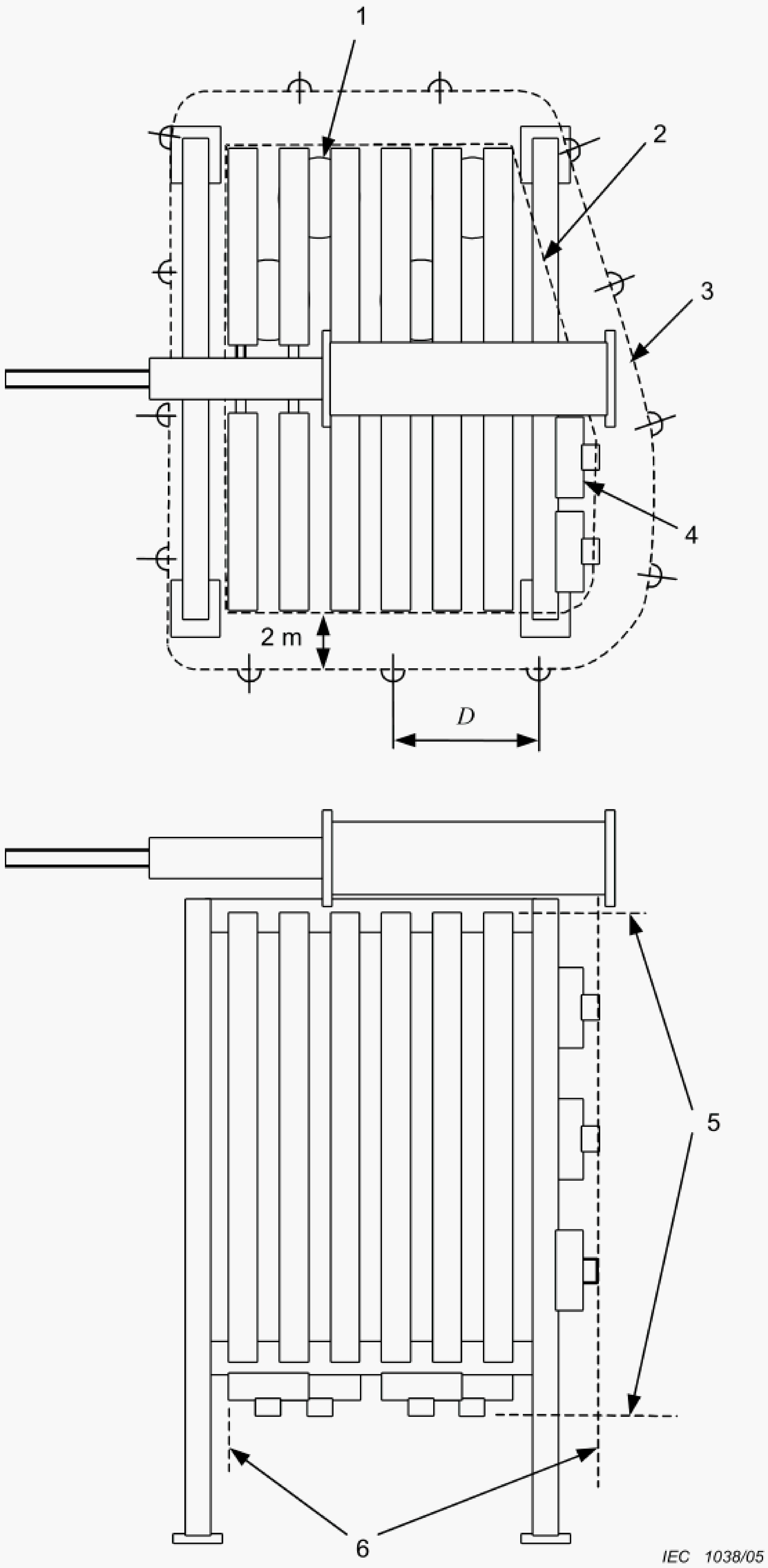
Figure 2 – Typical microphone positions for sound measurement on transformers having cooling auxiliaries mounted either directly on the tank or on a separate structure spaced <3 m away from the principal radiating surface of the main tank



Key

1	Principal radiating surface	*D*	Microphone spacing
2	Prescribed contour	*h*	Height of the tank
3	Transformer tank	*X*	Measurement distance
4	Forced air cooling		

Figure 3 – Typical microphone positions for sound measurement on transformers having separate forced air coolers 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

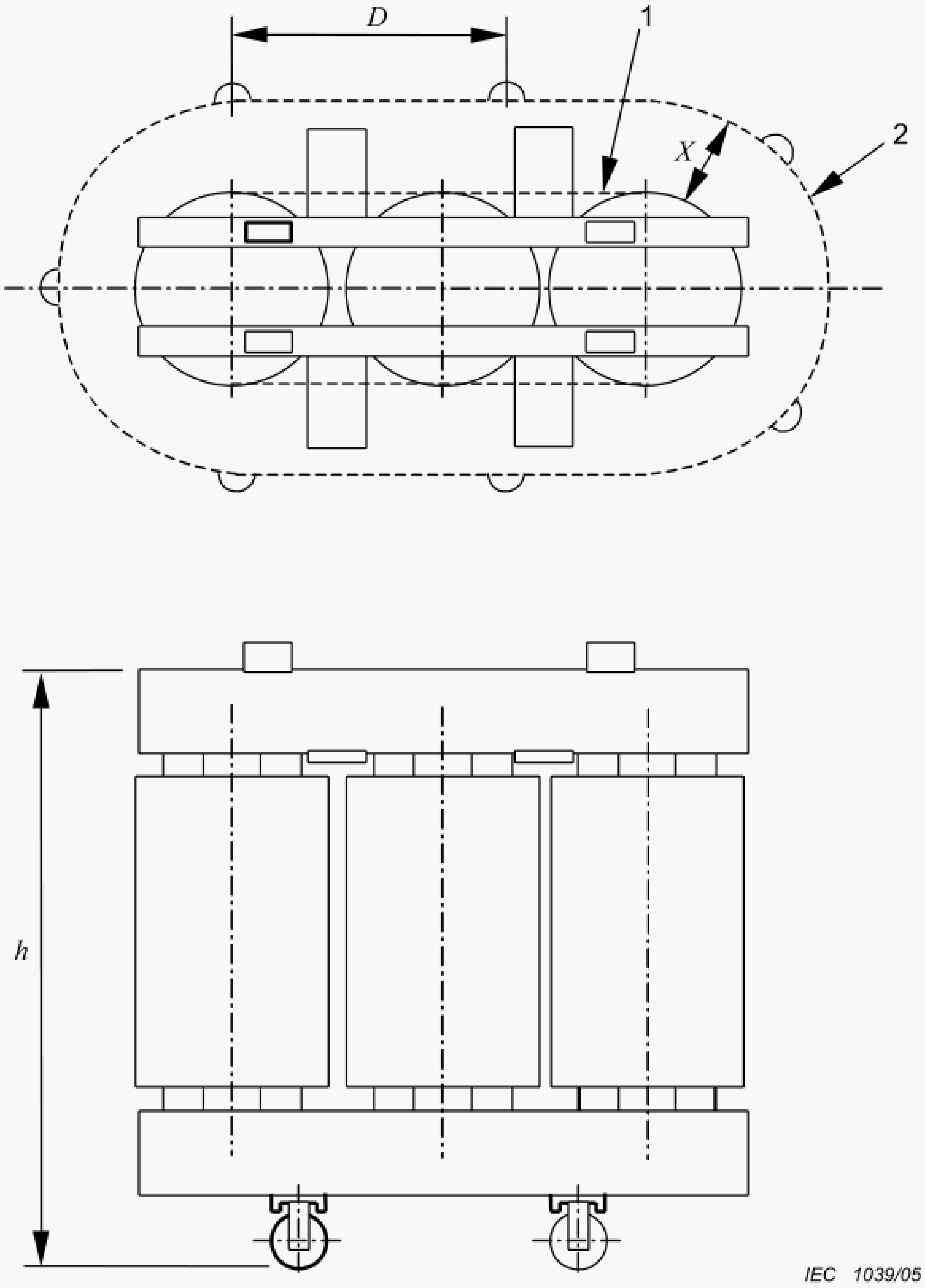
4 Horizontal forced air cooling

5 Horizontal boundaries of principal radiating surface

6 Vertical boundaries of principal radiating surface

D Microphone spacing

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



Key

1 Principal radiating surface

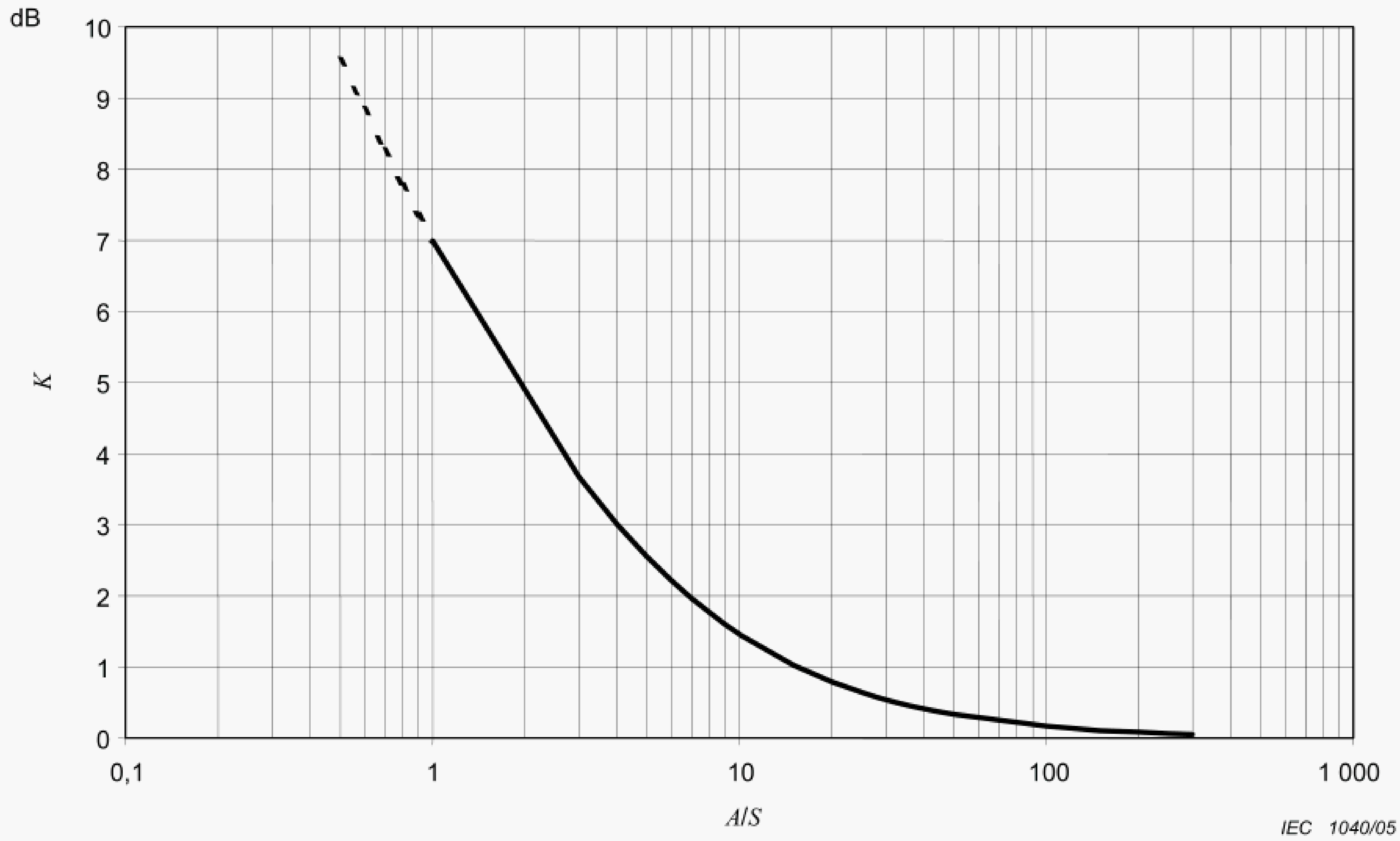
2 Prescribed contour

h Height of core with framework

D Microphone spacing

X Measurement distance

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



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

Figure 6 – Environmental correction, *K*

Annex A
(informative)

Narrow-band and time-synchronous measurements

A.1 Introduction

In circumstances where background noise levels lead to invalid results according to the criteria laid down in 11.3 and 12.3, narrow-band or time-synchronous measurements may offer a way to filter out unwanted signals. These methods cannot eliminate the effects of reflections described by the environmental correction K.

Transformer sound is characterized by tones at double the power frequency and at even harmonics of the power frequency. Therefore uncorrelated noise can be attenuated by applying time-synchronous averaging or narrow-band measurements at the relevant frequencies only.

Narrow-band and time-synchronous measurements can only be valid for tests made with any cooling equipment and oil circulating pumps out of service.

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 measurements

The analyzer bandwidth, Δf, should be chosen from the following: 1/10 octave or narrower, 10 % of the selected frequency or 5 Hz or 10 Hz bandwidths.

NOTE If the narrow-band measuring method is selected, the actual harmonic generated may fall outside the bandwidth of the measuring instrument when the frequency of the power supply is still within its permitted variation. If the measured supply frequency generates a harmonic frequency outside the chosen bandwidth (Δf), the acceptance of the measurement requires agreement between manufacturer and purchaser, or a wider bandwidth should be selected.

Measurements should be made as described in either Clause 11 or Clause 12 except that, instead of measuring single A-weighted values, the levels should be measured over bandwidths centred at frequencies equal to twice the rated frequency and multiples thereof. The A-weighted sound pressure level or sound intensity level at each measurement position can then be calculated by using equations (A.1) or (A.2):

$$L_{pAi} = 10\,\lg\left(\sum_{\nu=1}^{\nu_{max}} 10^{0,1 L_{pA\nu}}\right) \qquad (A.1)$$

where

L_{pAi} is the A-weighted sound pressure level at rated voltage and rated frequency;

$L_{pA\nu}$ is the A-weighted sound pressure level measured over the chosen bandwidth, Δf, centred on a frequency equal to $2f\nu$, at rated voltage and rated frequency;

f is the rated frequency;

ν is the sequence number (1, 2, 3, etc.) of multiples of the even harmonics of the rated frequency;

$\nu_{max} = 10$.

$$L_{IAi} = 10 \lg \left(\sum_{\nu=1}^{\nu_{max}} 10^{0,1 L_{IA\nu}} \right) \tag{A.2}$$

where

L_{IAi} is the A-weighted sound intensity level at rated voltage and rated frequency;

$L_{IA\nu}$ is the A-weighted normal sound intensity level measured over the chosen bandwidth, Δf, centred on a frequency equal to $2f\nu$ at rated voltage and rated frequency;

f is the rated frequency;

ν is the sequence number (1, 2, 3, etc.) of multiples of the even harmonics of the rated frequency;

$\nu_{max} = 10$.

A.3 Time-synchronous measurements

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. By using a trigger signal synchronous with the transformer sound, for example, the network voltage, all non-synchronous noise will be eliminated.

NOTE 1 Many industrial noise sources may be synchronous. In these cases, the use of this method is not appropriate.

The attenuation of the ambient noise, N, depends on the number of averages, n, that are included in the measurement. The signal-to-noise ratio improvement in decibels, S/N, is equal to

$$S/N = 10 \lg n \tag{A.3}$$

This principle can be applied to both sound pressure and sound intensity measurements. For sound intensity measurements, results obtained by time synchronous averaging are valid for values of ΔL up to S/N + 8 dB(A).

NOTE 2 When time-synchronous measurements are made, it is essential that the microphone is kept in a fixed position relative to the transformer. To move the microphone continuously on the prescribed contour as described in Clause 9 is not possible in this case.

Annex B
(informative)

Typical report of sound level determination

Contract		Site	
Manufacturer		Place of manufacture	
Date of measurement			
Details of transformer			
Serial number		MVA	
Tapping range		Voltage ratio	
Connections		Rated frequency	Hz
Rated current	kA	Rated voltage	kV
Details of guaranteed level			
Sound pressure/power level	dB(A)	Measurement distance, X	m

TRANSFORMER / REACTOR WITHOUT COOLERS

TRANSFORMER / REACTOR WITH COOLERS

COOLERS WITHOUT TRANSFORMER / REACTOR

DRY-TYPE TRANSFORMER WITHOUT ENCLOSURE

DRY-TYPE TRANSFORMER WITH ENCLOSURE

DRY-TYPE TRANSFORMER WITH COOLERS INSIDE ENCLOSURE

Tap position

Details of measurement method

Measurement standard

Sound pressure / Sound intensity

A-weighted / Narrow-band / Time-synchronous (delete as appropriate)

Details of measuring instrument

Make	Meter type	Serial number
Microphone type	Serial number	

Calibration information

Test object

TRANSFORMER / REACTOR WITHOUT COOLERS

TRANSFORMER / REACTOR WITH COOLERS

COOLERS WITHOUT TRANSFORMER / REACTOR

DRY-TYPE TRANSFORMER WITHOUT ENCLOSURE

DRY-TYPE TRANSFORMER WITH ENCLOSURE

DRY-TYPE TRANSFORMER WITH COOLERS INSIDE ENCLOSURE

Plan of test object:

Including measuring positions, position of HV bushings, proximity of nearby sound reflecting surfaces, for example, equipment, walls, and positions for background noise measurements

Height(s) of microphone above ground:

Test conditions

Excitation voltage	kV
Frequency	Hz
Tap position	
Current at which measurements made (if appropriate)	A
Measurement distance, X	m
Length of prescribed contour(s), l_m	m
Height of test object, h	m
Area of measurement surface, S	m^2
$10\lg(S/S_0)$	

Assuming sound pressure method is used

A-weighted sound pressure levels of the background noise					
Plan position	At start of tests	At end of tests	Plan position	At start of tests	At end of tests
1			6		
2			7		
3			8		
4			9		
5			10		
			Arithmetic / energy average, $\overline{L_{bgA}}$		

A-weighted sound pressure levels, L_{pAi}								
Plan position	Height 1	Height 2	Plan position	Height 1	Height 2	Plan position	Height 1	Height 2
1			11			21		
2			12			22		
3			13			23		
4			14			24		
5			15			25		
6			16			26		
7			17			27		
8			18			28		
9			19			29		
10			20			30		
						Arithmetic / energy average, $\overline{L_{pA0}}$		

$\overline{L_{pA0}}$ – maximum $\overline{L_{bgA}}$ (must be ≥3 dB(A)) dB(A)

Environmental correction (must be ≤7 dB), K dB

Corrected average A-weighted sound pressure level, $\overline{L_{pA}}$ dB(A)

Calculated A-weighted sound power level, L_{WA} dB(A)

Assuming sound intensity method is used

A-weighted sound intensity and sound pressure measurements									
Plan position	Height 1		Height 2		Plan position	Height 1		Height 2	
	L_{IAi}	L_{pAi}	L_{IAi}	L_{pAi}		L_{IAi}	L_{pAi}	L_{IAi}	L_{pAi}
1					16				
2					17				
3					18				
4					19				
5					20				
6					21				
7					22				
8					23				
9					24				
10					25				
11					26				
12					27				
13					28				
14					29				
15					30				

Arithmetic/energy average $\overline{L_{pA0}}$ .... dB(A)

Arithmetic/energy average $\overline{L_{IA}}$ .... dB(A)

$\overline{L_{pA0}} - \overline{L_{IA}}$ (must be ≤8 dB(A)) .... dB(A)

Calculated A-weighted sound power level, L_{WA} .... dB(A)

For either sound pressure or sound intensity method

Remarks, additional results, etc. (including details of any significantly high sound pressure levels at positions other than the measuring positions):

Calculated A-weighted sound pressure level or sound power level $\overline{L_{pA}}$ *or* L_{WA}	dB(A)
Guaranteed sound pressure level or sound power level	dB(A)

Persons present during sound level measurements and their status

Signed:	Date:

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