NORME INTERNATIONALE
INTERNATIONAL STANDARD

CEI
IEC
551

Deuxième édition
Second edition
1987

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

Détermination des niveaux de bruit des transformateurs et des bobines d'inductance

Determination of transformer and reactor sound levels

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IEC
Vol. 8

Code prix 25
Price code

Pour prix, voir catalogue en vigueur
For price, see current catalogue

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

DETERMINATION OF TRANSFORMER AND REACTOR SOUND LEVELS

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE

This standard has been prepared by IEC Technical Committee No. 14: Power transformers.

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

Six Months' Rule	Report on Voting	Two Months' Procedure	Reports on Voting
14(CO)58	14(CO)66	14(CO)67 14(CO)68	14(CO)69 14(CO)70

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

The following IEC publications are quoted in this standard:

Publications Nos. 76: Power transformers.
76-1 (1976): Part 1: General.
289 (1968): Reactors.
651 (1979): Sound level meters.
726 (1982): Dry-type power transformers.

Other publication quoted:

ISO Standard 3746 (1979): Acoustics – Determination of sound power levels of noise sources – Survey method.

DETERMINATION OF TRANSFORMER AND REACTOR SOUND LEVELS

1. Scope

This standard defines the methods by which the sound levels of transformers, reactors and their associated cooling equipment shall be determined so that compliance with any specification requirements may be confirmed and the characteristics of the noise emitted in service determined.

This standard is intended to apply to measurements made in the manufacturer's works since conditions may be very different when measurements are made on site because of the proximity of other objects, background extraneous noises, etc. Nevertheless, the same general rules as are given herein may be followed when on-site measurements are made.

In those cases where sufficient power is available in the factory to permit full energization of reactors, the methods to be followed are the same as for transformers. Such measurements shall be made by agreement between the manufacturer and the purchaser. Alternatively, measurements may be made on site where conditions are suitable.

The methods are applicable to transformers and reactors covered by IEC Publications 76, 726 and 289, without further limitation as regards size or voltage and when fitted with their normal auxiliary equipment, inasmuch as it may influence the measurement result.

Although the following text refers only to transformers, it is equally applicable to reactors provided that it is recognized that the current taken by a reactor is dependent on the voltage applied and, consequently, that a reactor cannot be tested at no-load.

This standard provides a basis for calculation of sound power levels.

The methods of measurement and the environmental qualification procedure given in Appendix A are in accordance with ISO Standard 3746. Measurements made in conformity with this IEC standard tend to result in standard deviations which are equal to or less than 3 dB.

2. Definitions

For the purpose of this standard, the following definitions apply.

2.1 *Sound pressure level,* L_p

The value in decibels equal to twenty times the logarithm to the base of 10 of the ratio of the sound pressure to the reference sound pressure.

Note. — For the purposes of this standard, A-weighted values of L_p are used, i.e., L_{pA} = A-weighted sound pressure level, and the reference sound pressure is 20 μPa.

2.2 *A-weighted surface sound pressure level,* $\overline{L_{pA}}$

The A-weighted sound pressure level in decibels averaged over the measurement surface as required in Clause 6.

2.3 *Sound power level, L_W*

The value in decibels equal to ten times the logarithm to the base 10 of the ratio of a given sound power to the reference sound power.

Note. — For the purposes of this standard, A-weighted values of L_W are used, i.e. L_{WA} = A-weighted sound power level, and the reference sound power is 1 pW (10^{-12} W).

2.4 *Principal radiating surface*

A hypothetical surface surrounding the transformer or cooling equipment which is assumed to be the surface from which sound is radiated.

Note. — The method of determining the principal radiating surface for particular equipment is given in Sub-clause 5.2.

2.5 *Prescribed contour*

A horizontal line, spaced at a definite distance from the principal radiating surface, along which the measuring positions are located.

Note. — The method for determining the prescribed contour for particular equipment is given in Sub-clause 5.2.

2.6 *Measurement surface*

A hypothetical surface of area S which envelops the source and on which the measuring positions are located.

Note. — The methods for the determination of this area are given in Sub-clause 6.2.

2.7 *Measurement distance*

The distance between the principal radiating surface and the measurement surface.

2.8 *Background noise*

The A-weighted sound pressure level at each measuring position with conditions as given in Sub-clause 5.1, the test object being inoperative.

3. Instruments

Measurements shall be made using a Type 1 sound level meter complying with IEC Publication 651.

An acoustic check of the measuring equipment using a calibrated noise source shall be made immediately before and after the measurement sequence.

The instruments shall be calibrated in accordance with ISO Standard 3746.

4. Conditions for measurement

4.1 *Criteria for adequacy of the test environment*

Ideally, the test environment should be free from reflecting objects other than a reflecting floor so that the equipment under test radiates into a free field over a reflecting plane. Test environments that are suitable for measurements according to this standard are those which meet the qualification procedures of Appendix A.

4.2 *Operating conditions of equipment during measurement*

For measurements made on the transformer with or without its auxiliary cooling plant, the transformer shall be on no-load and excited at rated voltage of sinusoidal or practically sinusoidal waveform and rated frequency with the tap-changer (if any) on the principal tapping. The voltage shall be measured in accordance with Sub-clause 8.5 of IEC Publication 76-1.

If the transformer is fitted with reactor-type on-load tap-changer equipment and 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 as near as possible to the principal tapping. The excitation voltage shall be appropriate to the tapping in use.

Notes 1. — Under special conditions of intended application of the transformer (particularly under 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 should then be clearly indicated in the test report.

2. — If the supply is suddenly applied to the unit under test, it is advisable to delay noise measurements on large transformers for some minutes after the instant of switching.

4.3 *Quantities to be measured*

The A-weighted sound pressure levels shall be measured for the transformer and the background noise sources. To avoid measurement errors due to disturbing influences, the fast response indication of the meter shall be used.

5. Measurement of sound pressure levels

5.1 *Background noise measurement*

The A-weighted sound pressure level of the background noise shall be measured immediately before and after the measurement on the transformer.

If the background sound pressure level is clearly much lower than the combined level of the background and transformer (difference not less than 10 dB), measurements of 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.

If the background sound pressure level is such that the difference in dB, between the combined sound pressure level of the transformer plus the background and the background sound pressure level alone, is less than 10 dB but not less than 3 dB, the corrections shown in Sub-clause 5.3, Table I shall be applied. In such cases, the background level shall be determined at every measuring position.

Note 1. — When the total number of measuring positions exceeds 10, it is permissible to measure the background sound pressure level at only 10 positions equally distributed around the transformer.

If the difference is less than 3 dB, the test will not be valid unless the combined level of the background and transformer noise is less than the guaranteed value. In such a case, the lower value for this difference will be taken and the combined level minus 3 dB may be regarded as the upper value of the sound pressure level of this position. This condition shall be recorded in the test report.

Note 2. — While the present standard permits a small difference between the background noise level and that resulting from the combination of the equipment and background noise, every effort should be made to obtain a difference of at least 6 dB.

The height(s) of the microphone(s) during the background noise measurements shall be the same as for the measurements of the noise of the transformer and the background measurements shall be taken at points on the prescribed contour(s).

5.2 *Sound pressure level measurements for the transformer*

The following measurement methods cover the different types of cooling employed, depending on whether the coolers are less than or more than 3 m away from the principal radiating surface of the main tank. They also permit the sound power level of the complete equipment to be calculated.

While the text of Sub-clauses 5.2.2 and 5.2.3 refers only to air cooling, the same principles as set out therein apply to measurements on transformers equipped with water coolers.

Notes 1. — In the case of certain equipment, it may be necessary to apply test specifications (height of the prescribed contour and its distance to the object to be tested) different from those indicated hereafter.

These test specifications should be according to the relevant standards if any, or be subject to agreement between manufacturer and purchaser.

In the case of transformers with horizontal high-voltage bushings, the contour used has to be determined by safety considerations. This may be achieved by confining the contour to the safe zone. (See Sub-clause 6.2, *e)*.)

2. — With the use of storage type measuring equipment with an averaging device and thereby shorter measuring and recording times, the microphone can be moved with constant speed on the prescribed contour around the transformer and/or cooling equipment for determining the energy average of the sound pressure level. The number of recorded readings shall be not less than the number of measuring positions specified herein.

3. — In the figures showing typical microphone positions the spacing between measuring positions is indicated by *D*.

5.2.1 *Transformers having no forced air cooling auxiliaries or with forced air cooling auxiliaries mounted on a separate structure spaced not less than 3 m away from the principal radiating surface of the main tank. Dry-type transformers in enclosures and dry-type transformers with forced air coolers inside the enclosure*

Measurements on the transformer only are to be made in accordance with this Sub-clause 5.2.1; those on any forced air cooling auxiliaries are to be made in accordance with Sub-clause 5.2.3 below.

The principal radiating surface is the surface obtained by the vertical projection, 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, of a string contour encircling the transformer. (See Figure 1, page 28.) The principal radiating surface shall include cooling equipment attached to the tank, tank stiffeners and such auxiliary equipment as cable boxes, tap-changer, etc., and exclude any forced air cooling auxiliaries. Projections such as bushings, oil pipework, oil conservators, tank underbase, valves and other secondary elements shall also be excluded.

The prescribed contour shall be spaced 0.3 m away from the principal radiating surface as defined above.

For transformers with a tank height less than 2.5 m, the prescribed contour shall be on a horizontal plane at half the tank height.

For transformers with a tank height equal to or greater than 2.5 m, two prescribed contours shall be used which are on horizontal planes at one-third and two-thirds of the tank height.

Because of the distance between the prescribed contour and the forced air cooling auxiliaries, no account need be taken of the proximity of such auxiliaries when arranging the measuring positions. Any oil circulating pumps and forced air cooling equipment shall be out of service during the measurements on the transformer.

The measuring positions shall be approximately equally spaced and not more than 1 m apart with a minimum number of six (see Figure 1, page 28).

5.2.2 *Transformers having forced air cooling auxiliaries or water cooling equipment mounted either directly on the tank or on a separate structure spaced less than 3 m away from the principal radiating surface of the main tank* (see note below)

Two sets of measurements shall be made, both with the transformer energized:

1) with the forced air cooling equipment and any oil circulating pumps out of service; and
2) with the forced air cooling equipment and any oil circulating pumps in service.

The principal radiating surface is the surface obtained by the vertical projection from the top of the transformer tank cover (excluding bushings, turrets and other accessories situated above the tank cover, see Figure 1) to the base of the tank, of a string contour encircling the apparatus. The principal radiating surface shall include the forced air cooling auxiliaries, tank stiffeners and such auxiliary equipment as cable boxes, tap-changer, etc.

Projections such as bushings, oil pipework, oil conservators, tank or cooler underbases, valves, control cubicles and other secondary elements shall be excluded.

For the purpose of measurements 1), the prescribed contour shall be spaced 0.3 m away from the principal radiating surface. For the purpose of measurements 2), the prescribed contour shall be spaced 2 m away from the principal radiating surface. (See distance X in Figures 2 and 3, pages 29 and 30).

For transformers with a tank height less than 2.5 m the prescribed contour shall be on a horizontal plane at half the tank height.

For transformers with a tank height equal to or greater than 2.5 m, two prescribed contours shall be used which are on horizontal planes at one-third and two-thirds of the tank height.

The measuring positions shall be approximately equally spaced and not more than 1 m apart, with a minimum number of 10 (see Figure 2, for transformers having forced air cooling auxiliaries mounted on the tank and Figure 3 for transformers having these auxiliaries mounted on a separate structure).

Note. — Where the transformer is designed and intended for enclosure and the cooler, external to the enclosure, is spaced less than 3 m away from the transformer, then the procedure given in Sub-clauses 5.2.1 and 5.2.3 should be followed.

5.2.3 *Forced air cooling auxiliaries or water cooling equipment mounted on a separate structure spaced not less than 3 m away from the principal radiating surface of the transformer*

These measurements are in addition to those made on the main equipment. They shall be made with the transformer unenergized and with all forced air cooling equipment and oil circulating pumps in operation. These measurements shall be regarded as additional requirements, unless otherwise specified, since it is often not the practice to erect separate cooling equipment at the manufacturer's works except when temperature-rise tests are being made on the main equipment.

The principal radiating surface is the surface obtained by the vertical projection from the top of the cooler structure to the base of the active parts (see Figure 4, page 31) of a string contour encircling the apparatus but excluding oil conservators, framework, pipework, valves and other secondary elements.

The prescribed contour shall be spaced 2 m away from the principal radiating surface as defined above.

For cooler structures with an overall height less than 4 m (excluding oil conservators, pipework, etc.), the prescribed contour shall be on a horizontal plane at half the height. For cooler structures with an overall height (excluding oil conservators, pipework, etc.) equal to or greater than 4 m, two prescribed contours shall be used which are on horizontal planes at one-third and two-thirds of the height.

The measuring positions shall be approximately equally spaced and not more than 1 m apart, with a minimum number of 10 (see Figure 5, page 32).

5.2.4 *Dry-type transformers without enclosures*

The principal radiating surface is the surface obtained by the vertical projection from the top of the transformer structure to the base of the active parts (see Figure 6, page 33) of a string contour encircling the dry-type transformer excluding framework, external wiring and connections and attached apparatus not affecting the sound radiation.

The prescribed contour shall be spaced 0.3 m away from the principal radiating surface as defined above unless for safety reasons 1 m is chosen. The measuring positions shall be approximately equally spaced and not more than 1 m apart with a minimum number of six (see Figure 6).

5.3 *Corrections for background noise*

The sound pressure levels recorded at each of the measuring positions according to Sub-clause 5.2 shall be corrected for the influence of background noise according to Table I.

The background noise is measured according to Sub-clause 5.1.

TABLE I

Correction for influence of background noise

Difference between sound pressure level measured with the equipment operating and background sound pressure level alone	Correction to be subtracted from sound pressure level measured with the equipment operating to obtain sound pressure level due to the equipment
dB	dB
3	3
4-5	2
6-8	1
9-10	0.5

6. Calculation of surface sound pressure level and sound power level

6.1 *Calculation of surface sound pressure level*

An A-weighted surface sound pressure level, $\overline{L_{pA}}$, shall be calculated from the measured values of the A-weighted sound pressure level, L_{pAi} (after corrections are applied according to Sub-clause 5.3, Table I, if necessary) by using the equation:

$$\overline{L_{pA}} = 10 \log_{10} \left[\frac{1}{N} \sum_{i=1}^{N} 10^{0.1\, L_{pAi}} \right] - K \qquad (1)$$

where:

$\overline{L_{pA}}$ = A-weighted surface sound pressure level, in decibels—Reference: 20 μPa

L_{pAi} = A-weighted sound pressure level at the i^{th} measuring position corrected for the background noise according to Table I, in decibels—Reference: 20 μPa

N = Total number of measuring positions

K = Environmental correction to account for the influence of reflected sound, in decibels. The procedure for the calculation is given in Appendix A

The environmental correction K typically ranges from 0 dB (for measurements outdoors) to more than 10 dB for measurements indoors in highly reverberant rooms.

For the purposes of this standard, the maximum allowable value of the environmental correction K is 7 dB.

Notes 1. — To get the A-weighted surface sound pressure level $\overline{L_{pA}}$ it is also possible to correct the energy average of the measured values according to Sub-clause 5.2 with respect to the energy average of the background noise level according to Sub-clause 5.1. The correction for the environmental influence is made as shown in equation (1).

2. — 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 (1).

3. — Due to the specific harmonic tone-content of transformer noise it is possible that standing waves may be an additional influence of the environment on measured sound pressure levels (L_{pAi}). In this case the application of a single correction factor does not suffice. Therefore the measurements should be performed, whenever possible, in surroundings where "environmental-influence" correction is not necessary.

6.2 *Calculation of the area of the measurement surface*

a) Measurements on transformers energized and forced air cooling auxiliaries unenergized, as indicated in Sub-clauses 5.2.1, 5.2.2 1) and 5.2.4 made at 0.3 m from the principal radiating surface.

The area S of the measurement surface, expressed in square metres, is calculated by the formula:

$$S = 1.25\, h\, l_m \qquad (2)$$

where:

h = height in metres of the transformer tank, or alternatively the height of the core and its framework in the case of dry-type transformers without enclosures

l_m = length of the prescribed contour in metres

1.25 = empirical factor intended to take account of the sound energy radiated by the upper part of the transformer or coolers

b) Measurements on transformers energized with forced air cooling auxiliaries also energized, as indicated in Sub-clause 5.2.2 2), made at 2 m from the principal radiating surface.

The area S of the measurement surface, expressed in square metres, is calculated by the formula:

$$S = (h + 2)\, l_m \qquad (3)$$

where:

h = height of the transformer tank, in metres

l_m = length of the prescribed contour, in metres

2 = measurement distance, in metres

c) Measurements on forced air cooling auxiliaries mounted separately from the transformer, as indicated in Sub-clause 5.2.3, made at 2 m from the principal radiating surface.

The area S of the measurement surface, expressed in square metres, is calculated by the formula:

$$S = (H + 2)\, l_m \qquad (4)$$

where:

H = height of the cooling equipment, including fans, in metres (see Fig. 4, page 31)

l_m = length of the prescribed contour, in metres

2 = measurement distance, in metres

d) Measurements on dry-type transformers energized as indicated in Sub-clause 5.2.4, made at 1 m from the principal radiating surface.

The area S of the measurement surface, expressed in square metres, is calculated by the formula:

$$S = (h + 1)\, l_m \qquad (5)$$

where:

h = height of core with framework, in metres

l_m = length of the prescribed contour, in metres

1 = measurement distance, in metres

e) Measurements on transformers where safety clearance considerations require a measurement distance which for all or part of the prescribed contour exceeds the provisions of Items *a)* to *d)* above.

The area S of the measurement surface, expressed in square metres, is calculated by the formula:

$$S = \frac{3}{4\pi}\, l_m^2 \qquad (6)$$

where:

l_m = length of the prescribed contour, in metres, as dictated by safety clearances

6.3 *Calculation of sound power level*

The A-weighted sound power level of the equipment L_{WA} shall be calculated from the equation:

$$L_{WA} = \overline{L_{pA}} + 10 \log_{10} \frac{S}{S_0} \qquad (7)$$

where:

L_{WA} = A-weighted sound power level, in decibels—Reference: 10^{-12} W

S = area of the measurement surface, in square metres—Reference: S_0 = 1 m²

For transformers with forced air cooling equipment mounted directly on the tank (see Sub-clause 5.2.2), the sound power level of the cooling equipment L_{WA0} in decibels is:

$$L_{WA0} = 10 \log_{10} (10^{\,0.1\, L_{WA1}} - 10^{\,0.1\, L_{WA2}}) \qquad (8)$$

where:

L_{WA1} = sound power level of the transformer + cooling equipment in decibels (see Sub-clause 5.2.2)

L_{WA2} = sound power level of the transformer in decibels (see Sub-clause 5.2.1)

Note. — If the sound power levels of the individual fans and pumps of a cooling equipment according to Sub-clause 5.2.3 are known, the total sound power of the cooling equipment can be obtained by adding together the individual values on an energy basis (analogous to equation (1)). This method of determining the sound power level of cooling equipment is subject to agreement between manufacturer and purchaser.

For transformers with forced air cooling equipment mounted on a separate structure (see Sub-clause 5.2.3) the sound power level of the transformer plus cooling equipment L_{WA1} in decibels is calculated by using the equation:

$$L_{WA1} = 10 \log_{10} (10^{0.1 L_{WA2}} + 10^{0.1 L_{WA0}}) \quad (9)$$

where:

L_{WA2} = the sound power level of the transformer, in decibels (see Sub-clause 5.2.1)

L_{WA0} = the sound power level of the cooling equipment, in decibels (see Sub-clause 5.2.3)

Note. — For approximate calculation of the A-weighted sound pressure level L_{pAR} in decibels at a distance R in metres ($R >$ about 30 m) from the geometrical centre of the equipment, the following equation is used:

$$L_{pAR} = L_{WA} - 10 \log_{10} \frac{S_h}{S_0} \quad (10)$$

where:

L_{WA} = A-weighted sound power level in decibels

S_h = $2\pi R^2$ = area of the surface of a hemisphere of radius R, in square metres—Reference: $S_0 = 1$ m²

7. Presentation of results

The report shall include such of the following information as is applicable to the equipment of which the sound level has been measured:

a) Reference to this measurement standard.

b) A description of the transformer giving rated power, voltage and voltage ratio, connections, etc.

c) The name of the transformer maker and the place of manufacture.

d) The characteristics of the sound measuring equipment and method of verification of its calibration. This information shall include the serial numbers of the instrument, of the microphones and of the calibration source.

e) A dimensioned sketch showing the position of the transformer with respect to other objects in the measurement area and the measuring positions.

f) The A-weighted sound pressure levels for each measuring position for the following operating conditions, with the transformer fully equipped:

1) transformer energized, its auxiliaries unenergized;
2) transformer energized, its auxiliaries energized;
3) transformer unenergized, its auxiliaries energized.

g) The A-weighted sound pressure levels of the background noise for each measuring position.

h) The A-weighted sound pressure levels for each measuring position corrected for background noise level.

i) The environmental correction K calculated according to Appendix A.

j) The A-weighted surface sound pressure level $\overline{L_{pA}}$ for operating conditions 1), 2) and 3) of Sub-clause 7 *f)* as applicable.

k) The area S of the measurement surface for measurements at 0.3 m away from the principal radiating surface.

l) The area S of the measurement surface for measurements at 2 m away from the principal radiating surface.

m) The area S of the measurement surface for measurements at 1 m away from the principal radiating surface (see Sub-clause 5.2.4).

n) The A-weighted sound power level(s) for operating conditions 1), 2) and 3) of Sub-clause 7 *f)*, as applicable. The value(s) shall be rounded to the nearest whole decibel.

Note. — A typical form for the presentation of results is given on pages 26 and 27.

REPORT OF SOUND LEVEL MEASUREMENT

Contract number and site .....

Manufacturer ..... Place of measurement ..... Date of measurement .....

Place of manufacture ..... Measurement specification .....

Details of transformer:

Serial No. ..... MVA ..... Voltage ratio ..... Connections .....

Tapping range .....

Details of measuring instrument:

Make ..... Type ..... Serial No. .....

Microphone type ..... Microphone serial No. .....

Calibration data of instrument and microphone .....

.....

.....

Test conditions:

Excitation voltage ..... Frequency ..... Hz Tap position .....

A-weighted sound pressure levels $\overline{L_{pA}}$

Transf./Reactor without coolers
Transf./Reactor with coolers
Coolers without Transf./Reactor
Dry-Type-Transf. without enclosure
Dry-Type-Transf. with enclosure
} Delete as appropriate

Plan position	dB 1	2	3	Plan position	dB 1	2	3	Plan position	dB 1	2	3	Plan position	dB 1	2	3
1				13				25				37			
2				14				26				38			
3				15				27				39			
4				16				28				40			
5				17				29				41			
6				18				30				42			
7				19				31				43			
8				20				32				44			
9				21				33				45			
10				22				34				46			
11				23				35				47			
12				24				36				48			
												arithmetic/energy average			

1 = noise of the equipment; 2 = background noise; 3 = corrected noise of the equipment

Environmental correction K [ ]

$\overline{L_{pA}}$ [ ]

Area of effective surface:

a) for measurements at 0.3 m from the principal radiating surface ..... m^2
b) for measurements at 2 m from the principal radiating surface ..... m^2
c) for measurements at 1 m from the principal radiating surface ..... m^2

$10 \log_{10} \frac{S}{S_0}$ [ ]

L_{WA} [ ]

For the French text, see page 24.

Plan of transformer, indicating measuring positions with respect to the H.V. bushings, proximity of nearby sound reflecting surfaces, e.g. equipment, walls, etc., and positions of background noise level measurement.

Height of microphone(s) above ground ..... and ..... metres.

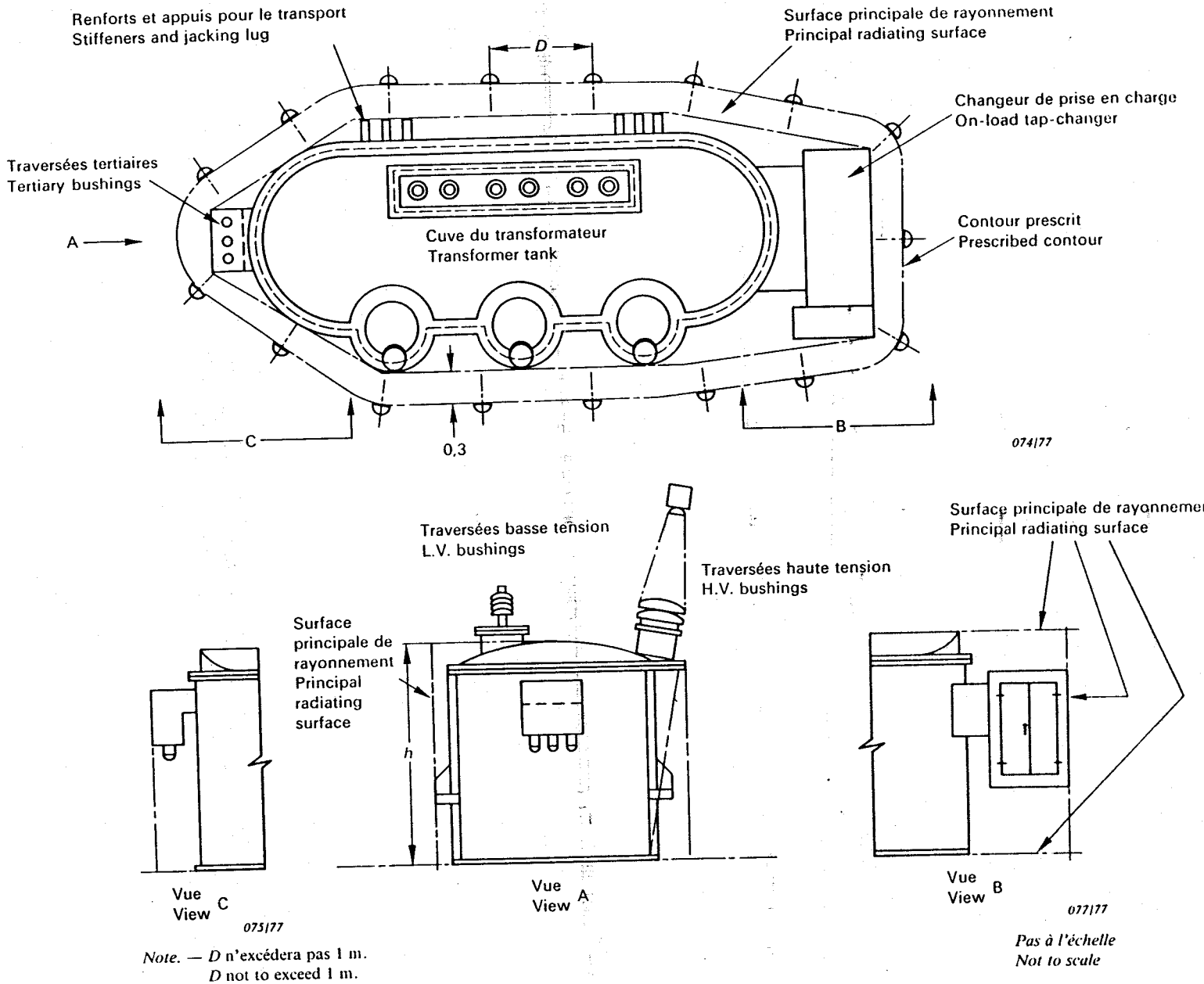
Remarks, additional results, etc. (including details of any significantly high sound pressure levels at positions other than the measuring positions):

A-weighted sound power level, guaranteed values:

Persons present during sound level measurements:

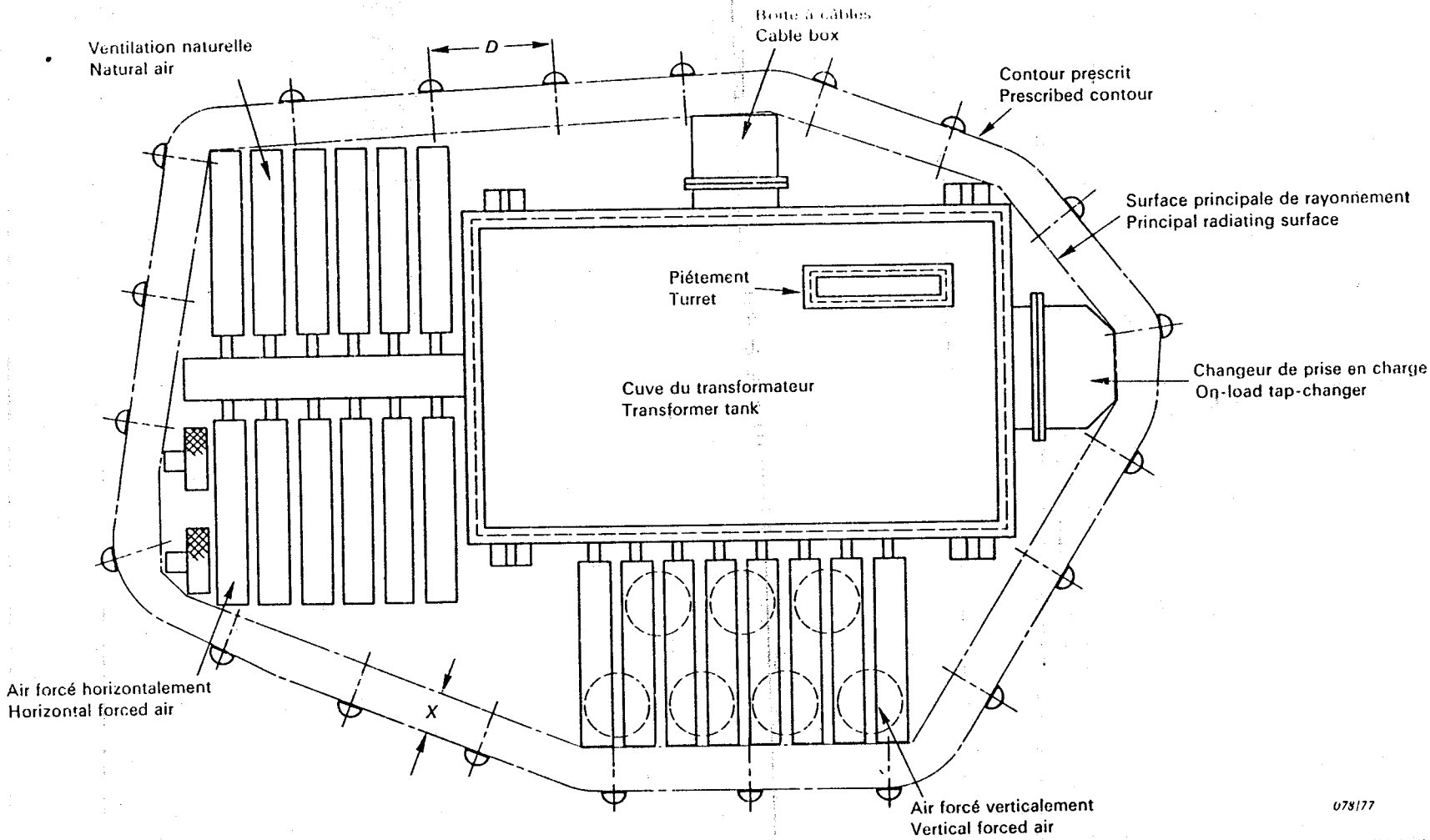
Signed ..... *Date* .....

For the French text, see page 25.



Note. — *D* n'excédera pas 1 m.
D not to exceed 1 m.

FIG. 1. — Positions types du microphone pour les mesures du bruit des transformateurs sans réfrigération.
Typical microphone positions for noise measurement on transformers excluding cooling equipment.

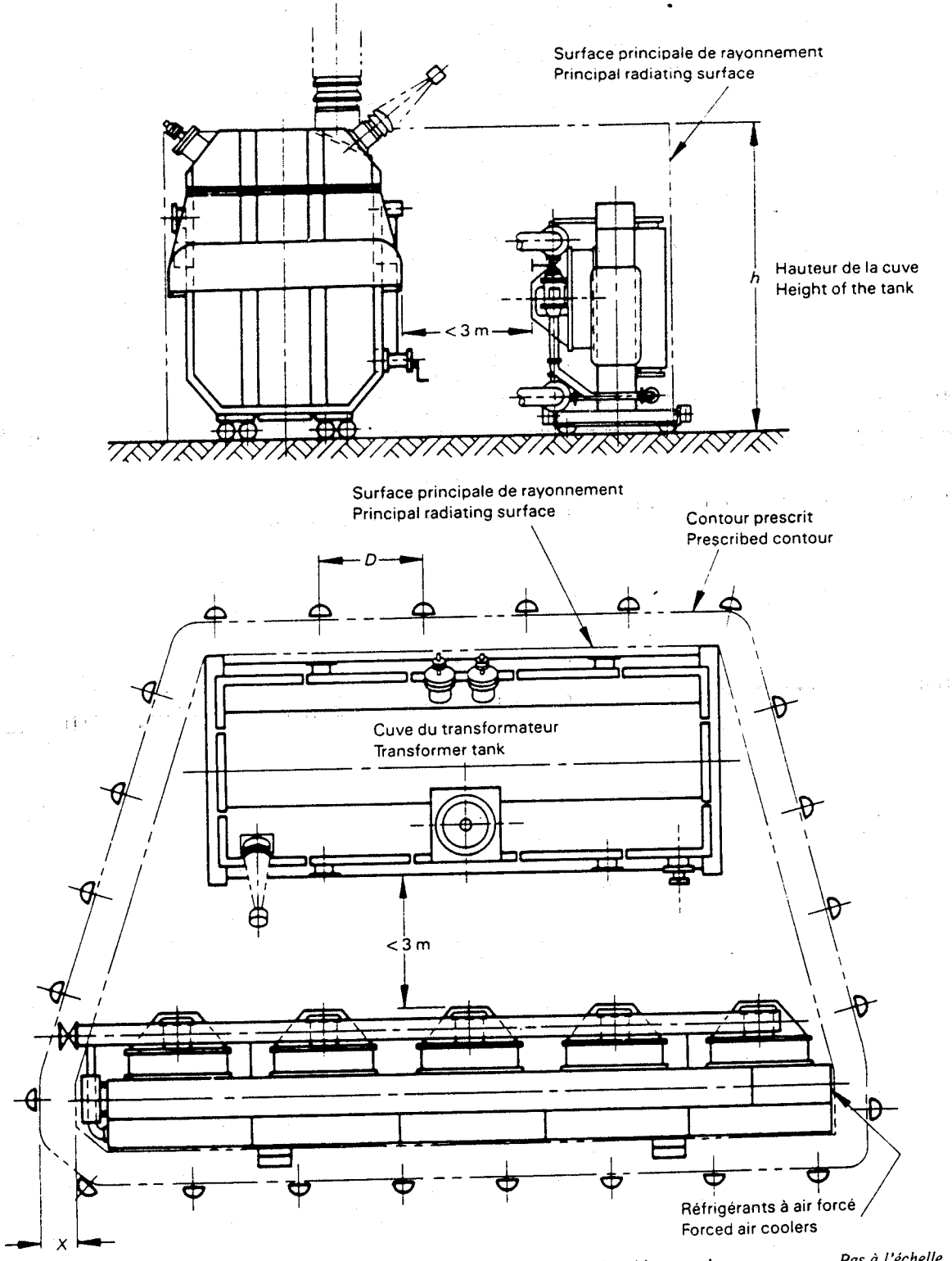


Pas à l'échelle
Not to scale

Notes 1. — La distance *X* est 0,3 m ou 2 m, voir le paragraphe 5.2.2
Distance *X* is 0.3 m or 2 m, see Sub-clause 5.2.2.

2. — *D* n'excédera pas 1 m.
D not to exceed 1 m.

FIG. 2. — Positions types du microphone pour les mesures du bruit des transformateurs dont les réfrigérants à air forcé sont montés directement sur la cuve ou sur un châssis séparé éloigné de moins de 3 m de la surface principale de rayonnement de la cuve du transformateur.
Typical microphone positions for noise measurement on transformers having forced air cooling auxiliairies either mounted directly on the tank or on a separate structure spaced less than 3 m away from the principal radiating surface of the transformer tank.

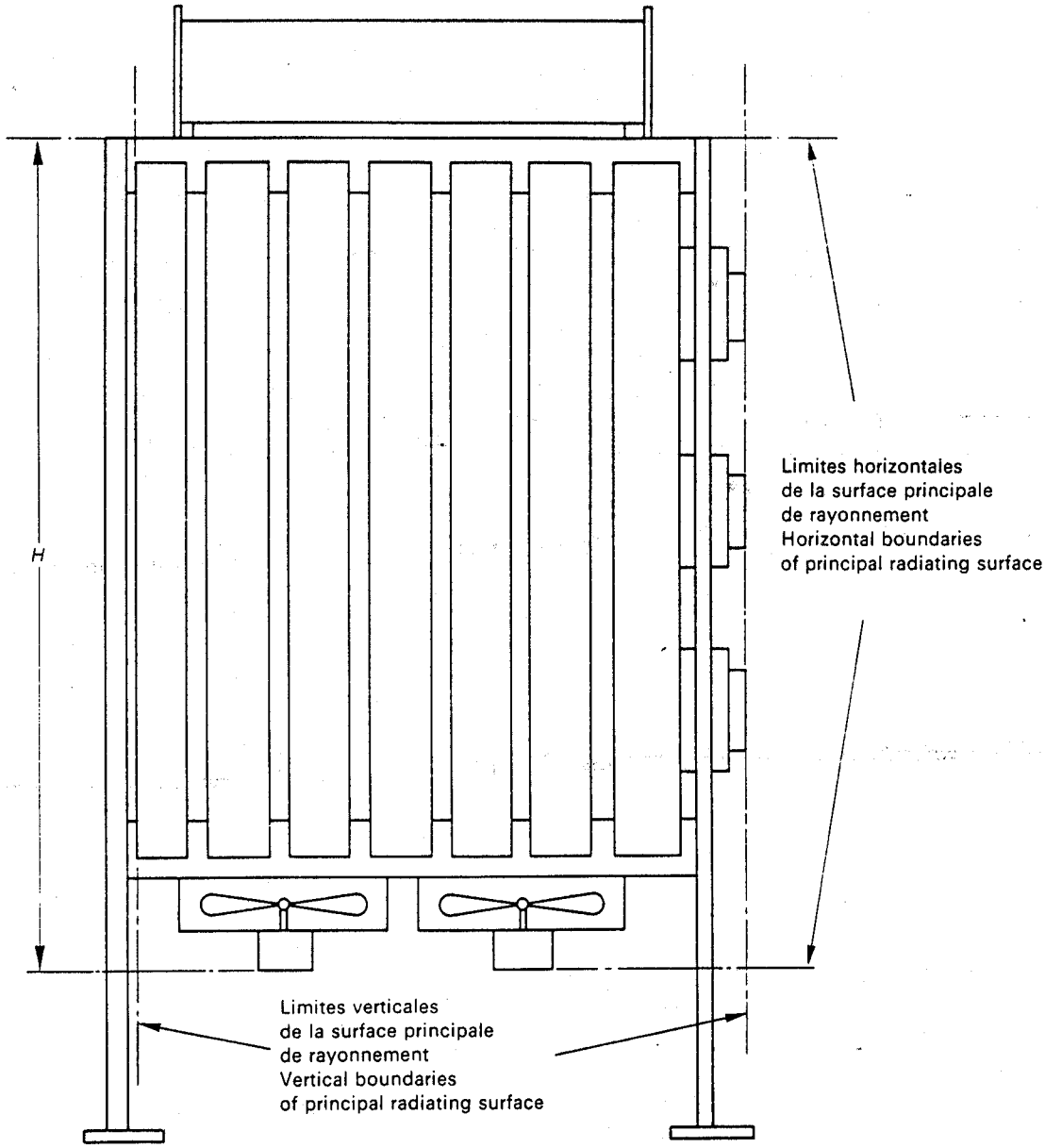


Notes 1. — La distance *X* est 0,3 m ou 2 m, voir le paragraphe 5.2.2.
Distance *X* is 0.3 m or 2 m, see Sub-clause 5.2.2.

2. — *D* n'excédera pas 1 m.
D not to exceed 1 m.

Pas à l'échelle
Not to scale

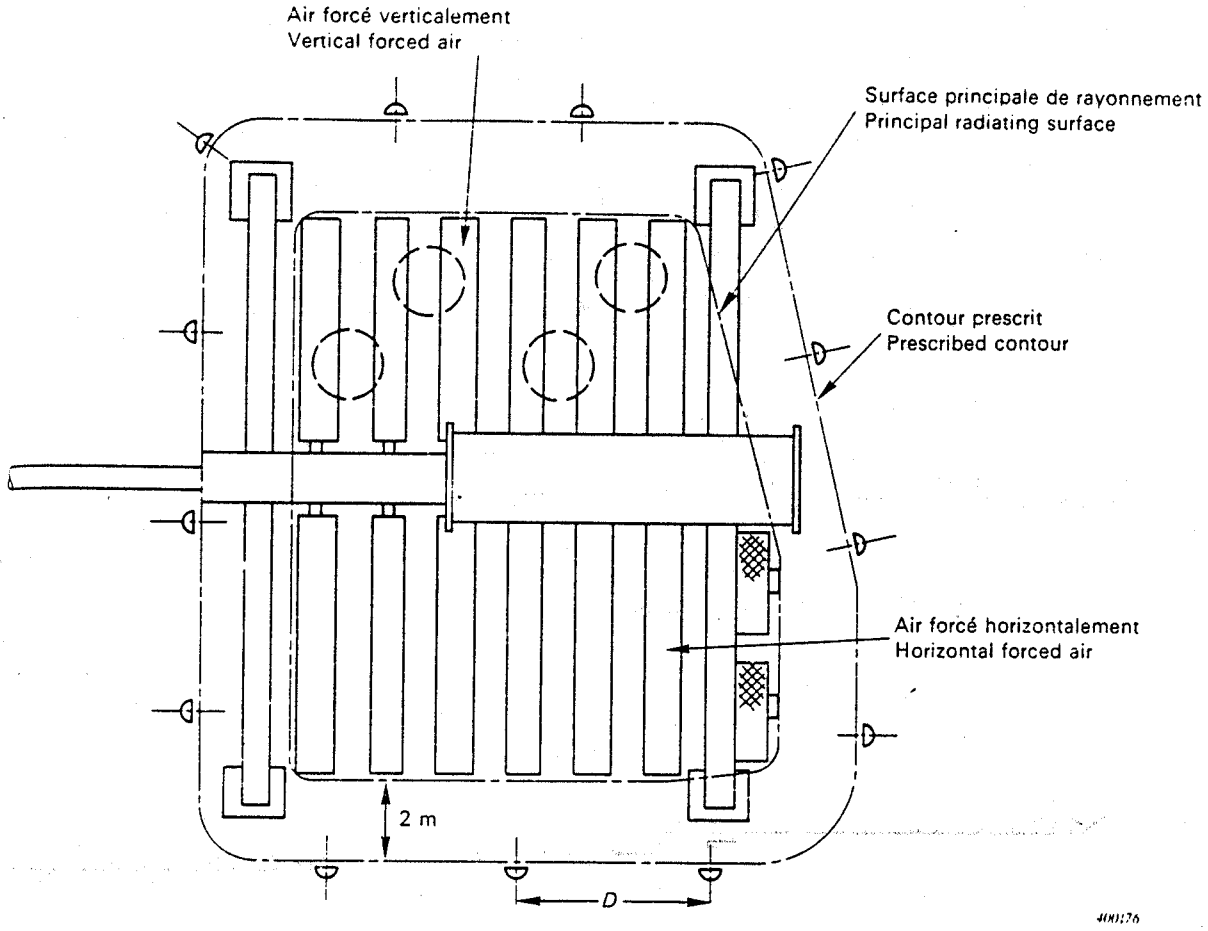
FIG. 3. — Positions types du microphone pour les mesures du bruit des transformateurs pourvus de réfrigérants à air forcé séparés, éloignés de moins de 3 m de la surface principale de rayonnement de la cuve du transformateur.
Typical microphone positions for noise measurement on transformers with separate forced air coolers spaced less than 3 m away from the principal radiating surface of the transformer tank.



VUE EN ÉLÉVATION
ELEVATION VIEW

Pas à l'échelle
Not to scale

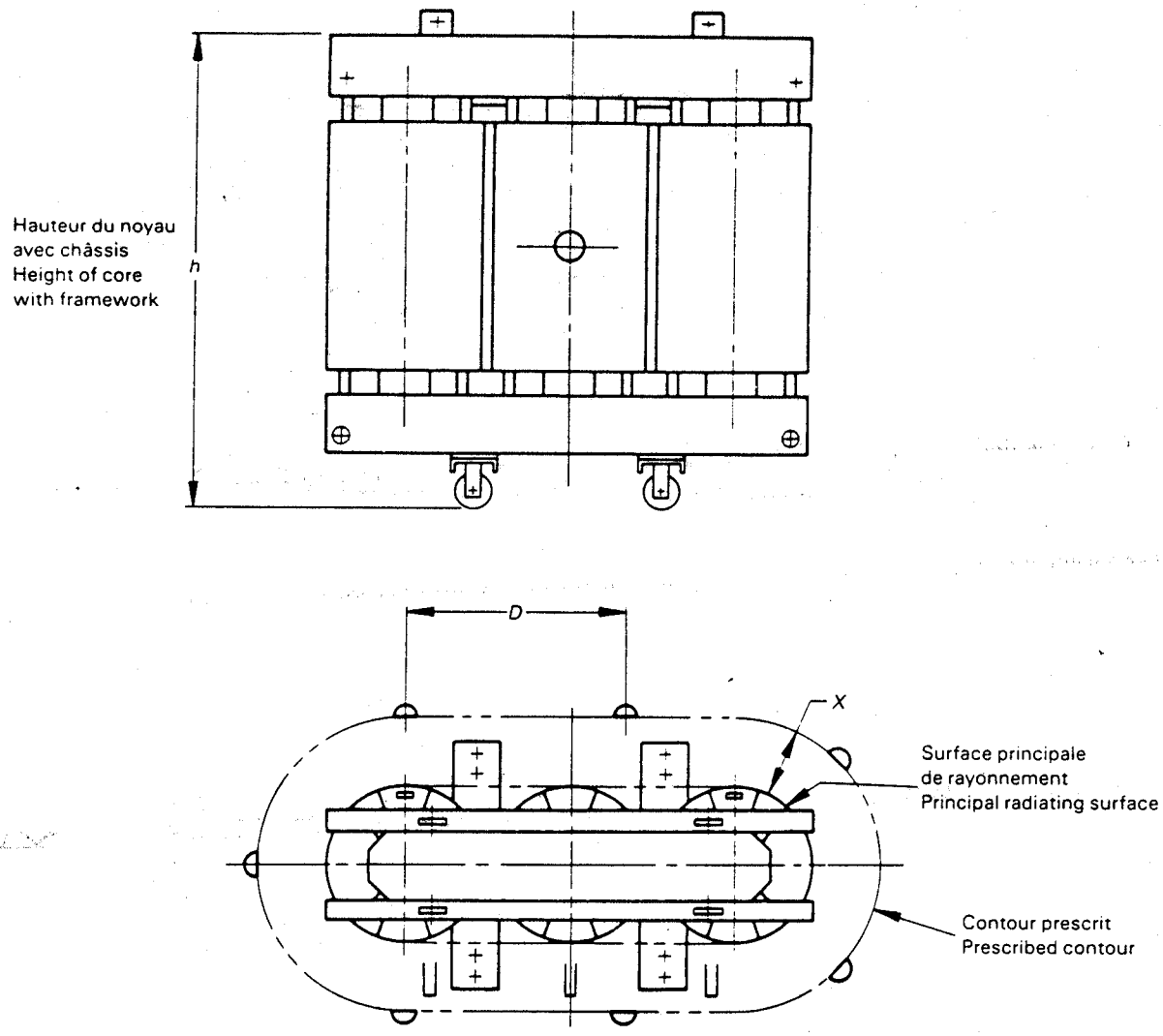
FIG. 4. — Batterie de refroidissement à air forcé représentant les limites de la surface principale de rayonnement.
Cooler with forced air cooling auxiliaries showing boundaries of principal radiating surface.



D n'excédera pas 1 m.
D not to exceed 1 m.

Pas à l'échelle
Not to scale

FIG. 5. — Positions types du microphone pour les mesures du bruit des batteries de refroidissement à air forcé montées sur un châssis séparé éloigné d'au moins 3 m de la surface principale de rayonnement de la cuve du transformateur.
Typical microphone positions for noise measurement on forced air cooling auxiliaries mounted on a separate structure spaced not less than 3 m away from the principal radiating surface of the transformer tank.



Notes 1. — La distance *X* de 0,3 m ou 1 m, voir le paragraphe 5.2.4.
Distance *X* is 0.3 m or 1 m, see Sub-clause 5.2.4.

2. — *D* ne doit pas dépasser 1 m.
D not to exceed 1 m.

Pas à l'échelle
Not to scale

FIG. 6. — Positions types du microphone pour les mesures du bruit sur les transformateurs de type sec sans enveloppe.
Typical microphone positions for noise measurement on dry-type transformers without enclosures.

APPENDIX A

TEST ENVIRONMENT QUALIFICATION PROCEDURE

A1. General

An environment providing an approximately free field over a reflecting plane shall be used for measurements made according to this standard. The environment may be provided by a suitable test area outdoors or by an ordinary room if the requirements given in this appendix are satisfied.

Reflecting objects shall be removed to the maximum extent possible from the vicinity of the equipment under test with the exception of the reflecting plane. A test room shall ideally provide a hypothetical measurement surface which lies:

a) inside a sound field essentially undisturbed by reflections from nearby objects and the room boundaries, and

b) outside the near field of the sound source under test for the purposes of this standard.

For the purposes of this survey method of environmental qualification at frequencies ≥ 100 Hz, the measurement surface is considered to lie outside the near field if the measurement distance from the source under test is equal to or greater than 0.25 m.

For outdoor measurements, the prescribed conditions of Clause A2 shall be satisfied. For indoor measurements, one of the alternative qualification procedures of Clause A3 shall be followed. Otherwise, the measurements will not be in conformity with the requirements of this standard.

A2. Environmental conditions

A2.1 *Types of reflecting planes*

For outdoor measurements, the reflecting plane may be undisturbed earth or an artificial surface of concrete or sealed asphalt. For indoor measurements, the reflecting plane is usually the floor of the room.

Note. — When the reflecting surface is not a ground plane or the floor of the test room, care should be taken to ensure that the reflecting surface does not radiate any appreciable sound energy due to vibrations.

A2.1.1 *Shape and size*

The reflecting surface shall be larger than the projection of the measurement surface on it.

A2.1.2 *Acoustic absorption coefficient*

The acoustic absorption coefficient of the reflecting plane should 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.

For reflecting planes with higher acoustic absorption coefficients, for example, grass- or snow-covered ground, the measurement distance shall be not greater than 1 m. For indoor measurements, wooden and tile floors are permitted.

A2.2 *Reflecting objects*

No reflecting objects that are not part of the source under test shall be located inside the measurement surface.

A2.3 *Precautions for outdoor measurements*

It should be realized that adverse meteorological conditions (for example, temperature gradients, wind gradients, precipitation and humidity) may all affect the measurements. Measurements should be avoided during extreme meteorological conditions.

In all cases, the precautions of the manufacturer as stated in the instruction manuals for the instruments shall be observed.

A3. Qualification procedure and requirements for test rooms

A3.1 *Test procedures*

The environmental correction K in equation (1) of Sub-clause 6.1 accounts for the influence of undesired sound reflections from room boundaries and/or reflecting objects near the source under test. The magnitude of this environmental correction K depends principally on the ratio of the sound absorption area A of the test room to the area S of the measurement surface. The magnitude does not depend strongly on the location of the source in the test room.

In this standard, the environmental correction K is obtained from Figure A1 by entering the abscissa with the appropriate value of A/S. The area S of the measurement surface is calculated from one of the equations given in Sub-clause 6.2. An alternative procedure for determining the value of K is given in Clause A5.

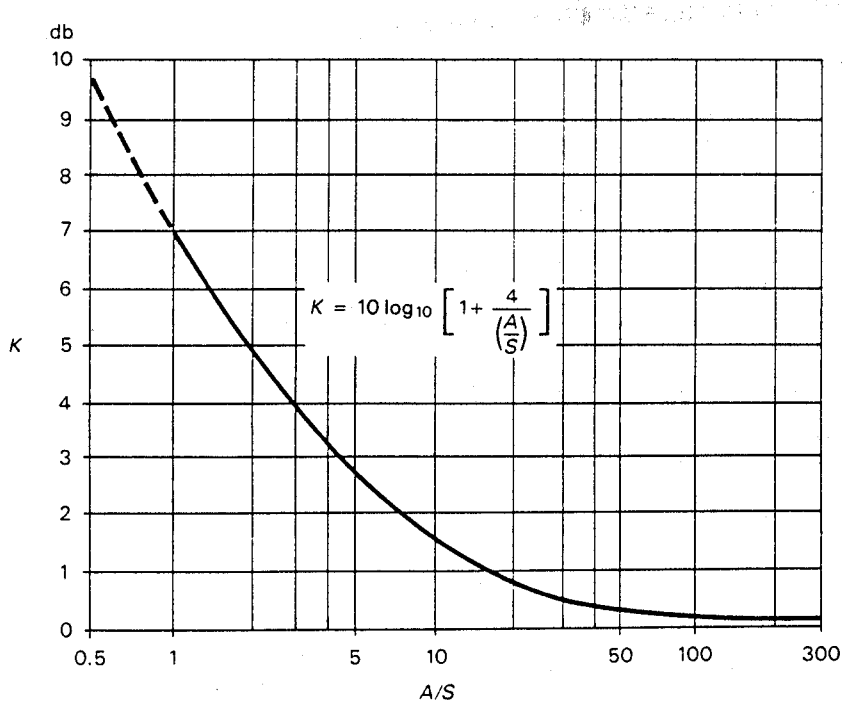


FIG. A1. — Environmental correction K, in decibels.

Two alternative methods are given to determine the total sound absorption area A of the test room.

A3.1.1 *Estimate of the sound absorption area A*

The mean acoustic absorption coefficient α of the surfaces of the room is estimated by using Table AI. The value of A in square metres is given by the formula:

$$A = \alpha S_v$$

where:

α is the mean acoustic absorption coefficient (see Table AI)
S_v is the total area of the surface of the test room (walls, ceiling and floor), in square metres

TABLE AI

Approximate values of the mean acoustic absorption coefficient α

Mean acoustic absorption coefficient α	Description of room
0.05	Nearly empty room with smooth hard walls made of concrete, brick, plaster or tile
0.1	Partly empty room, room with smooth walls
0.15	Room with furniture, rectangular machinery room, rectangular industrial room
0.2	Irregularly shaped room with furniture, irregularly shaped machinery room or industrial room
0.25	Room with upholstered furniture, machinery or industrial room with a small amount of acoustical material (for example, partially absorptive ceiling) on ceiling or walls
0.35	Room with acoustical materials on both ceiling and walls
0.5	Room with large amounts of acoustical materials on ceiling and walls

A3.1.2 *Experimental determination of the sound absorption area A*

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 noise or an impulsive sound with A-weighting on the receiving system. The value of A is given, in square metres, by the expression:

$$A = 0.16\,(V/T)$$

where:

V is the volume of the test room, in cubic metres
T is the reverberation time of the test room, in seconds

A3.2 *Qualification requirements for test rooms*

For the measurement surface in a test room to be satisfactory for measurements according to the requirements of this standard, the ratio of the sound absorption area A to the area S of the measurement surface shall be equal to or greater than 1, that is:

$$A/S \geq 1$$

The larger the ratio A/S is, the better.

If the above requirement cannot be satisfied, a new measurement surface shall be chosen. The new measurement surface shall have a smaller total area, but shall still lie outside the near field (see Clause A1). Alternatively, the ratio A/S may be increased by introducing additional sound absorptive materials into the test room and then redetermining the value of the ratio A/S under the new conditions.

If the requirement of this clause cannot be satisfied for any measurement surface which lies outside the near field of the source under test, the particular environment cannot be used for measurements on the source under test according to the requirements of this standard.

A4. Qualification requirements for outdoor spaces

For very large rooms as well as for workspaces which are not totally enclosed, the value of the environmental correction K is approximately equal to zero.

For measurements outdoors, the reflecting plane shall have the properties defined in Sub-clause A2.1 and the background noise levels shall meet the requirements of Sub-clause 5.1.

A5. Alternative test procedure

The correction K may be determined alternatively by calculating the 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 is given by the expression

$$K = L_W - L_{Wr}$$

where:

L_W is the sound power level, reference 1 pW, in decibels, of the reference sound source, which is determined according to the procedures of Clauses 7 and 8 of ISO Standard 3746 without the environmental correction K (i.e. it is initially assumed that $K = 0$)

L_{Wr} is the calibrated sound power level of the reference sound source, reference 1 pW, in decibels

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AMENDMENT 1

1995-08

Amendement 1

Détermination des niveaux de bruit des transformateurs et des bobines d'inductance

Amendment 1

Determination of transformer and reactor sound levels

Bureau Central de la Commission Electrotechnique Internationale 3, rue de Varembé Genève, Suisse

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

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FOREWORD

ormateurs This amendment has been prepared by IEC technical committee 14: Power transformers.

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

DIS	Rapport de vote
14/226/DIS	14/230/RVD

ur le vote Full information for the voting for the approval of this amendment can be found in the report on voting indicated in the above table.

Page 3

CONTENTS

Add the titles of annexes B and C as follows:

B – Derivation of sound power level from sound intensity measurements

C – Determination of sound power level due to load currents

Page 5

PREFACE

te: *Add, after IEC 726, the title of the following new publication:*

stique – IEC 1043: 1993, *Electroacoustics – Instruments for the measurement of sound intensity – Measurements with pairs of pressure sensing microphones*

Add, after ISO Standard 3746 (1979), the title of the following new publication:

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

Add, after the references, the following text:

Annexes A, B and C form an integral part of this standard.

Page 7

1 Scope

Insert the following new text between the second and third paragraphs:

Standard measurements use the A-weighted sound pressure level as a measured variable. In case of difficult measuring conditions, sound intensity measurements are advantageous. This application is described in annex B.

According to this standard, measurements on transformers are made under no-load. If a transformer has a very low no-load noise, the noise due to load current can also influence the sound level. Annex C specifies the measurement conditions for the determination of the noise due to load current.

Page 9

2.3 *Sound power level, L_W*

Add the following new note:

NOTE 2 – If the A-weighted sound power level is determined by sound intensity measurements, it is designated L_{WAI}. See annex B.

Page 21

6.3 *Calculation of sound power level*

Add immediately after the definitions of the variables of equation (7), the following new note:

NOTE – The A-weighted sound power level of the equipment can also be calculated from the measurement of sound intensity. See annex B.

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Add, after annex A, the new annexes B and C:

Annex B
(normative)

Derivation of sound power level from sound intensity measurements

B.1 General

The sound power level can be calculated from the measurement of the sound intensity; this annex specifies a method for measuring the component of sound intensity normal to a measurement surface around transformers or reactors, and their associated cooling equipment.

The sound intensity measurement method has the following advantages as compared with the sound pressure measurement method:

– the determination of the correct sound power is possible regardless of whether the measurement surface lies within or outside the near field;

– the determination of the correct sound power is possible in the presence of noise fields where the sound pressure method gives such erroneous results that they are no longer authorized by this standard.

NOTE – When the measurement surface lies in the near field, sound intensity measurement will lead to values of power 2 dB to 4 dB less in comparison with the sound pressure method.

B.2 Definitions

For the purpose of this annex, the definitions in clause 2, and the following definitions apply.

All definitions are in accordance with ISO 9614-1.

B.2.1 *Normal sound intensity,* I_n

The sound intensity component in the direction normal to a measurement surface is defined by unit normal vector $\vec{n}$.

$$I_n = \vec{I} \times \vec{n} \qquad \text{(B.1)}$$

where

$\vec{I}$ is the active intensity vector;

I is the signed magnitude of $\vec{I}$;

$\vec{n}$ is the unit normal vector directed out of the volume enclosed by the measurement surface.

B.2.2 *Normal sound intensity level,* L_{In}

The value in decibels equal to ten times the logarithm to base 10 of the ratio of the absolute value of the normal sound intensity $|I_n|$ to the reference sound intensity, I_o.

$$L_{In} = 10 \log_{10}\left[\frac{|I_n|}{I_o}\right] \qquad \text{(B.2)}$$

where

I_o is the reference sound intensity, 10^{-12} W/m².

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

B.2.3 *Partial sound power,* P_i

The time-averaged rate of flow of sound energy through an element (segment) of a measurement surface, calculated by the formula:

$$P_i = I_{ni} \times S_i \qquad \text{(B.3)}$$

where

I_{ni} is the signed magnitude of the normal sound intensity component measured at position i on the measurement surface;

S_i is the area of the segment of surface associated with point i.

B.2.4 *Sound power, P_I*

The sound power P_I generated by a source is calculated by the formula:

$$P_I = \sum_{i=1}^{N} P_i \qquad \text{(B.4)}$$

and

$$|P_I| = \left| \sum_{i=1}^{N} P_i \right| \qquad \text{(B.5)}$$

where

N is the total number of segments of the measurement surface.

B.2.5 *Sound power level, L_{WI}*

The value in decibels equal to ten times the logarithm to base 10 of the ratio of the absolute value of the sound power $|P_I|$ to the reference sound power, P_0.

$$L_{WI} = 10 \log_{10} \left[\frac{|P_I|}{P_o} \right] \qquad \text{(B.6)}$$

where

$|P_I|$ is the magnitude of the sound power of the source;

P_o is the reference sound power, 10^{-12} W.

A-weighted values of L_{WI} are used for calculating the A-weighted sound power level L_{WAI}.

NOTE – When P_I is negative, L_{WI} is expressed as –XX dB.

B.3 Instruments

B.3.1 *General*

Sound intensity measurement equipment shall meet the requirements of IEC 1043. The frequency range of the measurement equipment shall be adapted to the frequency spectrum of the transformer operating condition (with/without forced air cooling auxiliaries).

B.3.2 *Calibration and field check*

The instrument and probe calibration shall be checked at least once a year according to IEC 1043.

Instruments shall be checked in the field prior to each series of measurements using either the field calibration procedure specified by the manufacturer or the following procedure.

Each microphone shall be calibrated. Afterwards, the probe shall be rotated 180° about a normal to its measurement axis, while maintaining its acoustic centre at a fixed point, which shall be one of the selected measurement positions. The average absolute difference between the magnitude of the two levels shall be less than 1,5 dB.

B.4 *Conditions for measurement*

B.4.1 *Criteria for adequacy of the test environment*

The measurement conditions shall meet the requirements specified in B.5.1.

B.4.2 *Operating conditions of equipment during measurement*

Conditions as described in 4.2.

B.5 *Measurement of sound intensity*

Sound intensity can be measured using either one of the following two methods:

method I: A-weighted sound intensity level;

method II: narrow-band intensity measurement.

B.5.1 *Test environment and background noise*

The environment and background noise influence the results of measurements.

A criterion for the influence of the test environment and the background noise is ΔL defined as:

$$\Delta L = \bar{L}_{pA} - \bar{L}_{IA} \qquad \text{(B.7)}$$

where

$\bar{L}_{pA}$ is the A-weighted surface sound pressure level, defined as:

$$\bar{L}_{pA} = 10 \log_{10} \left[\frac{1}{N} \sum_{i=1}^{N} 10^{0,1\, L_{pAi}} \right] \qquad \text{(B.8)}$$

and where

$\bar{L}_{IA}$ is the A-weighted surface sound intensity level, defined as:

$$\bar{L}_{IA} = 10 \log_{10} \left[\frac{1}{N} \sum_{i=1}^{N} 10^{0,1\, L_{IAi}} \right] \qquad \text{(B.9)}$$

where

L_{pAi} is the A-weighted local sound pressure level at measurement position i in decibels (reference: 20 μPa);

L_{IAi} is the A-weighted local normal sound intensity level at measurement position i in decibels (reference 10^{-12} Wm^{-2});

N is the total number of measurement positions.

NOTE – Negative signs must be taken into account in conformity with ISO 9614-1.

Acceptable limits for values of ΔL are identified in B.5.2.1.

B.5.2 *Transformer sound intensity level measurements*

Transformer or reactor sound intensity levels shall be measured in conformity with 5.2.

Two methods can be used for the measurement of sound intensity.

method I: A-weighted sound intensity level;

method II: narrow-band intensity measurement.

The choice of the method shall be agreed between the user and manufacturer.

The narrow-band spectrum analysis measurement method shall be permitted only when the fans and/or oil pumps of the transformer cooling equipment are not activated.

For narrow-band intensity measurements, the bandwidth of the measurement equipment shall be less than or equal to 5 Hz.

When using method II, the A-weighted sound intensity level $\bar{L}_{IA}$ of the transformer can be calculated by summation of the levels $\bar{L}_{IAv}$ measured at frequencies equal to twice the rated frequency and multiples thereof:

$$\bar{L}_{IA} = 10 \log_{10} \left[\sum_{v=1}^{v_{max}} 10^{0,1\,\bar{L}_{IAv}} \right] \text{dB(A)} \qquad \text{(B.10)}$$

where

$\bar{L}_{IA}$ is the A-weighted normal surface sound intensity level;

$\bar{L}_{IAv}$ is the A-weighted normal surface sound intensity level at a frequency equal to $(v \times 2f)$ of the averaged spectrum;

f is the rated frequency;

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

$v_{max} = 10$.

NOTE – If the narrow-band intensity 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 allowable bandwidth of the instrument ($\Delta f \leq 5$ Hz), the acceptance of the measurement requires agreement between manufacturer and purchaser.

B.5.2.1 *Applicability of intensity measurements*

In order to maintain standard deviations which are equal to or less than 3 dB(A) in accordance with clause 1, the greatest practicable allowable values for ΔL are:

method I: $\Delta L = \bar{L}_{pA} - \bar{L}_{IA} \leq 8$ dB(A);

method II: $\Delta L = \bar{L}_{pA} - \bar{L}_{IA} \leq 15$ dB(A).

These values are only valid if the following conditions are fulfilled:

- the background noise shall be randomly distributed (test field noise, factory noise);
- reflecting objects shall be removed to the maximum distance from the transformer.

A practical procedure will be to interpose, whenever possible, absorbing panels between the measurement surface and the nearby walls:

- measurements are allowed in the presence of two reflecting walls. The distance of each wall shall be at least 1,2 m from the prescribed contour;

– measurements are allowed in the presence of three reflecting walls. The distance of each wall shall be at least 1,8 m from the prescribed contour;

– measurements in transformer cells are not allowed.

B.5.2.2 *Time synchronous averaging*

Time synchronous averaging can be applicable for all conditions of ΔL. However, if the value of ΔL is found to be higher than the limiting values given in B.5.2.1, then the time synchronous averaging technique shall be used. By using a noise-synchronous trigger signal (for example: network voltage) all non-synchronous noise will be attenuated during time averaging. This technique is applicable because transformer noise is characterized by tones at double the network frequency and at the even harmonics of that frequency.

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

$$S/N \approx 10 \log_{10} n \qquad \text{(B.11)}$$

where

n is equal to the number of averages.

The allowable value of ΔL can then be increased by this ratio (S/N).

To avoid changes in the sound field caused by changes of transformer temperature, it is recommended that the time spent making measurements should be minimized.

B.6 Calculation of the sound power level from the surface sound intensity level

An A-weighted sound power level L_{WAI} shall be calculated from the measured values of the A-weighted surface sound intensity level from B.5.1 or B.5.2 and the surface area calculated by 6.2.

The following equation is applicable:

$$L_{WAI} = \bar{L}_{IA} + 10 \log_{10} \left(\frac{S}{S_o} \right) \qquad \text{(B.12)}$$

where

L_{WAI} is the A-weighted sound power level, in decibels (reference: 10^{-12} W);

S is the area of measurement surface, in square metres (reference: S_o = 1 m²).

B.7 Presentation

As described in clause 7[1)].

1) It will not be necessary to record and calculate the sound intensity levels for each measuring point if the measuring equipment internally calculates the surface sound intensity.

Annex C
(normative)

Determination of sound power level due to load currents

C.1 General

Load noise is defined as the noise emitted by the transformer on load in addition to its no-load noise. It is caused by electromagnetic forces resulting from the magnetic leakage fields of the windings and is proportional to the square of the current. Generally, the sources of this noise are the vibrations in the tank walls, magnetic shields and in the windings themselves.

It should be noted that, from practical experience, the load noise can be of the same order of magnitude as the no-load noise.

This annex specifies the operating conditions of the transformer set up in the testing bay for measurement of load noise, and the method to be used for summing the no-load and load noises.

C.2 Operating conditions of the transformer during measurement

The transformer shall be loaded with a current having a sinusoidal or near sinusoidal wave shape in accordance with 4.2. One winding shall be short-circuited and a sinusoidal voltage applied to the other winding at rated frequency shall be gradually increased until rated current flows in the first winding (see IEC 76-1, 3.4.7). The tap-changer, if any, shall be set to the principal tapping.

C.3 Measurement of transformer sound power level

The measurement shall be performed according to the conditions described in 5.2.1.

Two methods can be used for the measurement of the no-load and the load current sound power level:

method I: A-weighted sound power level;

method II: narrow-band sound power level.

The choice of method shall be agreed upon by the user and the manufacturer.

Method II shall be permitted only when the fans and/or oil pumps of the transformer cooling equipment are not activated.

For narrow-band sound measurements, the bandwidth of the measurement equipment shall be less than or equal to 5 Hz.

The A-weighted sound power level L_{WA} can be calculated by summation of the levels L_{WAv} measured at frequencies equal to twice the rated frequency and multiples thereof:

$$L_{WA} = 10 \log_{10} \left[\sum_{v=1}^{v_{max}} 10^{0,1 \times L_{WAv}} \right] \quad \text{(C.1)}$$

where

L_{WA} is the A-weighted sound power level, in decibels;

L_{WAv} is the A-weighted sound power level at frequency equal to ($v \times 2f$) of the averaged spectrum, in decibels;

f is the rated frequency;

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

$v_{max} = 10$.

NOTE – If the narrow-band intensity 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 allowable bandwidth of the instrument ($\Delta f \leq 5$ Hz), the acceptance of the measurement requires agreement between manufacturer and purchaser.

C.4 Calculation of sound power level from measurement at reduced current

If the measurements can only be performed at a reduced current, the sound power level at rated current may be calculated as follows:

$$L_{WA,\,IN} = L_{WA,\,IT} + 40 \log_{10} \frac{I_N}{I_T} \quad \text{(C.2)}$$

where

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

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

I_N is the rated current;

I_T is the reduced current.

The equation is valid for $I_T / I_N = 0,7$ to 1,0.

C.5 Addition of no-load and load noise levels

The maximum A-weighted sound power level of the transformer in operation shall be calculated from the following equation:

$$L_{WA,\,SN} = 10 \log_{10} \left(10^{0,1 \times L_{WA,\,UN}} + 10^{0,1 \times L_{WA,\,IN}}\right) \qquad \text{(C.3)}$$

where

$L_{WA,\,SN}$ is the maximum possible sound power level of the transformer in operation at rated voltage, rated current and rated frequency, in decibels. The actual value may be lower in practice owing to the correlation of the two sound sources;

$L_{WA,\,UN}$ is the sound power level of the transformer at rated voltage, rated frequency and no-load, in decibels;

$L_{WA,\,IN}$ is the sound power level of the transformer at short-circuit impedance voltage, rated current and rated frequency, in decibels (see clause C.2).

The noise of the cooling equipment shall be considered by inclusion in either $L_{WA,\,UN}$ or $L_{WA,\,IN}$.