INTERNATIONAL STANDARD

IEC 60076-10

First edition
2001-05

Power transformers –

Part 10:
Determination of sound levels

Transformateurs de puissance –

Partie 10:
Détermination des niveaux de bruit

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 10: Determination of sound levels

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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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.

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.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annexes A and B are for information only.

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 5: Ability to withstand short-circuit

Part 8: Application guide

Part 10: Determination of sound levels

The committee has decided that the contents of this publication will remain unchanged until 2008. At this date, the publication will be

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- withdrawn;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

A bilingual version of this publication may be issued at a later date.

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, Part 10-1: Determination of transformer and reactor sound levels – User guide (under consideration)

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 60726 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 normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60076. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 60076 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International standards.

IEC 60076 (all parts), *Power transformers*

IEC 60289:1988, *Reactors*

IEC 60651:1979, *Sound level meters*

IEC 60726:1982, *Dry-type power transformers*

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

IEC 61378 (all parts), *Convertor transformers*

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 Definitions

For the purpose of this part of IEC 60076, 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 60651 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:

$$L_{WA,IN} \approx 39 + 18 \lg \frac{S_r}{S_p} \qquad (4)$$

where

$L_{WA,IN}$ 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.