INTERNATIONAL STANDARD

IEC 60076-10-1

First edition
2005-10

Power transformers –

Part 10-1:
Determination of sound levels – Application guide

*This **English-language** version is derived from the original **bilingual** publication by leaving out all French-language pages. Missing page numbers correspond to the French-language pages.*

Reference number
IEC 60076-10-1:2005(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

Consolidated editions

The IEC is now publishing consolidated versions of its publications. For example, edition numbers 1.0, 1.1 and 1.2 refer, respectively, to the base publication, the base publication incorporating amendment 1 and the base publication incorporating amendments 1 and 2.

Further information on IEC publications

The technical content of IEC publications is kept under constant review by the IEC, thus ensuring that the content reflects current technology. Information relating to this publication, including its validity, is available in the IEC Catalogue of publications (see below) in addition to new editions, amendments and corrigenda. Information on the subjects under consideration and work in progress undertaken by the technical committee which has prepared this publication, as well as the list of publications issued, is also available from the following:

- **IEC Web Site (www.iec.ch)**

- **Catalogue of IEC publications**

  The on-line catalogue on the IEC web site (www.iec.ch/searchpub) enables you to search by a variety of criteria including text searches, technical committees and date of publication. On-line information is also available on recently issued publications, withdrawn and replaced publications, as well as corrigenda.

- **IEC Just Published**

  This summary of recently issued publications (www.iec.ch/online_news/ justpub) is also available by email. Please contact the Customer Service Centre (see below) for further information.

- **Customer Service Centre**

  If you have any questions regarding this publication or need further assistance, please contact the Customer Service Centre:

  Email: custserv@iec.ch
  Tel: +41 22 919 02 11
  Fax: +41 22 919 03 00

INTERNATIONAL STANDARD

IEC 60076-10-1

First edition
2005-10

Power transformers –

Part 10-1:
Determination of sound levels – Application guide

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

IEC

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE X

For price, see current catalogue

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 10-1: Determination of sound levels – Application guide

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of 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, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). 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. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60076-10-1 has been prepared by technical committee 14: Power transformers.

This standard is to be read in conjunction with IEC 60076-10.

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

FDIS	Report on voting
14/505/FDIS	14/513/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 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 (under consideration)
Part 7: Loading guide for oil-immersed power transformers
Part 8: Application guide
Part 10: Determination of sound levels
Part 10-1: Determination of sound levels – Application guide
Part 11: Dry-type transformers
Part 12: Loading guide for dry-type power transformers (under consideration)
Part 13: Self-protected liquid filled transformers
Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials
Part 15: Gas-filled-type power transformers (under consideration).

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.

POWER TRANSFORMERS –

Part 10-1: Determination of sound levels – Application guide

1 Scope

This part of IEC 60076 provides supporting information to help both manufacturers and purchasers apply the measurement techniques described in IEC 60076-10. The sources and characteristics of transformer and reactor sound are described. Practical guidance on making measurements is given, and factors that may influence the accuracy of the methods are discussed. This application guide also clarifies those factors which should be agreed between manufacturer and purchaser when specifying a transformer or reactor, and indicates why values measured in the factory may differ from those measured on site.

This application guide is applicable to transformers and reactors together with their associated cooling auxiliaries.

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 60076-10:2005, *Power transformers – Part 10: Determination of sound levels*

3 Basic physics of sound

3.1 Sound pressure, p

Sound may be defined as any pressure variation (in air, water or other elastic media) that the human ear can detect. The pressure variations travel through the medium (for the purposes of this document, air) from the source of the sound to the listener's ears. The number of cyclic pressure variations per second is called the 'frequency' of the sound, and is measured in hertz (Hz). The frequency of a sound produces its own distinctive tone or pitch. A transformer 'hum' is low frequency, fundamentally 100 Hz or 120 Hz, while a whistle is high frequency, typically above 3 kHz. The normal range of hearing for a healthy young person extends from approximately 20 Hz to 20 kHz.

A further characteristic used to describe a sound is the amplitude of the pressure fluctuations which is measured in pascals (Pa). The weakest sound that a healthy human ear can detect is strongly dependent on frequency; at 1 kHz it has an amplitude of 20 μPa. The threshold of pain corresponds to a sound pressure of more than a million times higher. Therefore, to avoid the use of large numbers, the decibel scale (dB) is used.

The dB scale is 'logarithmic' and uses 20 μPa as the reference level, p_0, which then corresponds to 0 dB. Sound pressure level L_p is defined in equation 1:

$$L_p = 10 \lg \frac{p^2}{p_0^2} \tag{1}$$

where p is the sound pressure measured by a microphone. Sound pressure is a scalar quantity, which means that it has magnitude only.

A useful aspect of the decibel scale is that it gives a better approximation to the human perception of relative loudness than the linear pascal scale. This is because the ear responds to sound logarithmically. However, the human ear does not respond by the same amount for each frequency, hence a suitable filter is required to ensure that the microphone measurements truly reflect the sound perceived by the ear. An internationally-standardized filter, termed 'A weighting', addresses this requirement.

3.2 Particle velocity, u

This quantity describes the oscillation velocity of the particles of the medium in which the sound waves are propagating. It is measured in metres per second, ms^{-1}.

3.3 Sound intensity, I

Sound intensity is a vector quantity describing the magnitude and direction of the nett flow of sound energy at a given position. It is the time-averaged product of the sound pressure and particle velocity at a given point.

$$I = \overline{p \times u} \tag{2}$$

It is measured in watts per square metre, Wm^{-2}. The direction of the energy flow is given by the phase angle between the sound pressure and particle velocity at the specific location. (sound pressure can be thought of as analogous to voltage while the particle velocity is analogous to current when considering the flow of electrical energy.) The normal sound intensity is the rate of sound energy flow through a unit area, measured in a direction normal (that is at 90°) to the specified unit area.

3.4 Sound power, W

A sound source radiates power into the surrounding air resulting in a sound pressure field. Sound power is the cause. Sound pressure is the effect. The sound pressure which is heard (or measured with a microphone) is dependent on the distance from the source and the acoustic environment. Therefore, the noisiness of a source cannot be quantified by simply measuring sound pressure alone. Instead, it is necessary to determine its sound power; this is independent of the environment and a unique descriptor of the noisiness of a sound source.

Sound power is the rate at which energy is radiated (energy per unit time) and is measured in watts.

3.5 Sound fields

3.5.1 General

A sound field is a region in which there is sound. It is classified according to the manner in which the sound waves propagate. The precise relationship between sound pressure and sound intensity is known in only the first two special cases described in 3.5.2 and 3.5.3.

3.5.2 The free field

This term describes sound propagation in an idealised free space where there are no reflections. Sound propagation from a point source in a free field is characterised by a 6 dB drop in sound pressure level and intensity level each time the distance from the source is doubled in the direction of sound propagation. This is also approximately correct when the distance from an extended source is large enough to treat it as a point source. These conditions hold in the open air when sufficiently far away from the ground and any walls, or in a fully anechoic chamber where all the sound that strikes the walls, ceiling or floor is absorbed.

NOTE IEC 60076-10 requires all sound measurements to be made over a reflecting surface. Therefore, measurements in fully anechoic chambers are not allowed.

3.5.3 The diffuse field

In a diffuse field, sound is reflected so many times that it travels in all directions with equal magnitude and probability, hence the same sound pressure level exists at all locations. This field is approximated in a reverberant room. According to the law of conservation of energy, an equilibrium condition will occur when the sound power absorbed by or transmitted through the enclosure equals the sound power emitted by the source. This phenomenon may result in very high sound pressure levels in environments having low sound absorption or transmission characteristics.

3.5.4 Active and reactive sound fields

Sound propagation involves energy flow, but there can be a measurable sound pressure when there is no nett propagation.

If sound pressure and particle velocity are in phase, the result is a totally active field. In this case, all energy emitted by the source is transmitted outwards.

In a pure reactive field, there is no nett energy flow; sound pressure is 90° out of phase with particle velocity. At any instant, energy may be travelling outward, but it will be returned at a later instant; the energy is stored as if in a spring. Averaged over a whole number of cycles, the nett energy transfer is zero and hence the measured sound intensity is zero.

In general, a sound field will have both active and reactive components.

3.5.5 Standing waves

Standing waves arise in sound fields as a result of reflections between a sound source and the boundaries of the sound field. For example, in a room, the existence of a standing wave of frequency, f, depends upon the distance, d, between the reflecting walls as follows:

$$f = \frac{c}{2d} \tag{3}$$

where c is the speed of sound in air in m/s. At 20 °C, c = 343 m/s.

A standing wave does not transmit energy to the far field; it is an example of a reactive field. Within the region of a standing wave, large variations in measured sound pressure will occur over small distances.

3.5.6 The near-field

The near-field is a region close to a sound source, usually defined as within a distance of ¼ of the wavelength of the tone to be measured. In this region, the air acts as a mass-spring system that stores energy that circulates without propagating. The near-field therefore can have a significant reactive component.

At 20 °C in air, the wavelength of a 100 Hz tone is 3,4 m, while that of a 1 kHz tone is 0,34 m.

4 Sources and characteristics of transformer and reactor sound

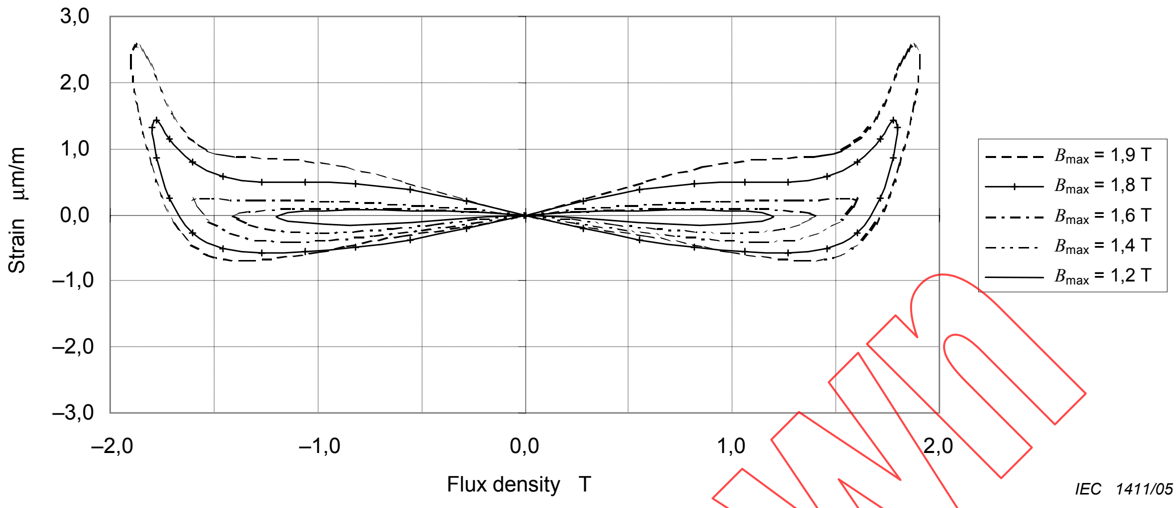
4.1 General

Transformer and reactor sound have several origins. The relative importance of each mode of sound generation depends on the design of the equipment and its operating conditions. The design of the transformer or reactor will also modify the sound-producing vibrations as they travel from their origin to the transformer tank or enclosure surface.

4.2 Sources

4.2.1 Magnetostriction

Magnetostriction is the change in dimensions, which is observed in certain materials when they are subjected to a change in magnetic flux. In magnetic core steel, the dimensional change is in the range of 10^{-7} to 10^{-5} metres per metre length at typical induction levels. Figure 1 shows magnetostriction vs. flux density for one type of core lamination measured at five different flux densities. Each loop describes one 50 Hz cycle with flux density B_{max}.



IEC 1411/05

Figure 1 – Example curves showing relative change in length for one type of core lamination during complete cycles of applied 50 Hz a.c. induction up to different peak flux densities B_{max} = 1,2 T – 1,9 T

NOTE For a given quality of steel, the mechanical stress in the core laminations will have a strong influence on the magnetostriction.

The strain does not depend on the sign of the flux density, only on its magnitude and orientation relative to certain crystallographic axes of the material. Therefore, when excited by a sinusoidal flux, the fundamental frequency of the dimensional change will be twice the exciting frequency. The effect is highly non-linear, especially at high, near saturation, induction levels. The non-linearity will result in a significant harmonic content in the vibration spectrum of the core. Figure 2 shows magnetostriction under oscillating induction to B = 1,8 T, 50 Hz. It has a periodicity of twice the exciting frequency (and its harmonics) and the peaks at 5 ms and 15 ms are indistinguishable.

The sound emitted by transformer cores depends on the velocity of the vibrations, i.e. the time derivative of the magnetostriction (dotted line) seen in Figure 2. The effect of derivation is to emphasise the harmonics (distortion) of the signal in relation to the fundamental 2 × exciting frequency. Several even multiples of the exciting frequency will be seen in the spectrum and the fundamental 2 × exciting frequency is seldom the most important frequency component of the sound.

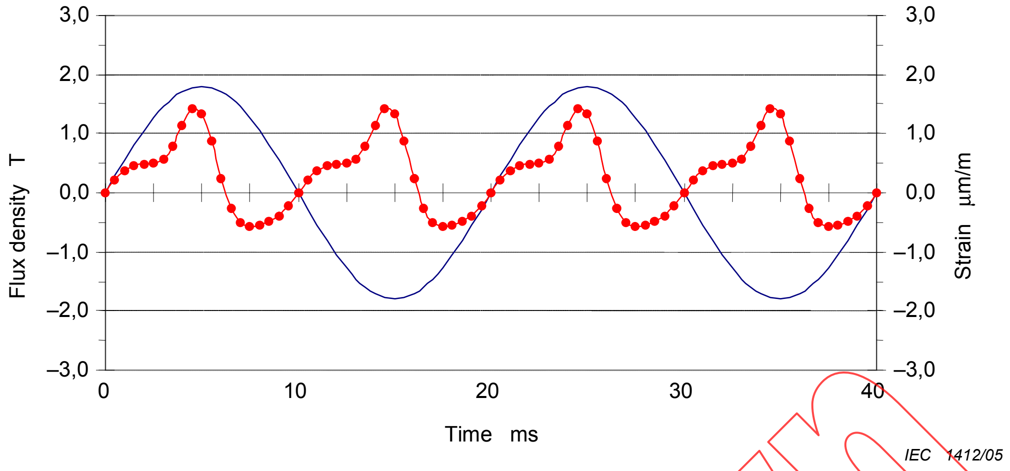


Figure 2 – Induction (smooth line) and relative change in lamination length (dotted) as a function of time due to applied a.c. induction: 1,8 T, 50 Hz – no d.c. bias

If the flux has a d.c. bias, for example due to remanence in the core from preceding measurements of the windings' resistance, or due to a d.c. component in the current, the strong non-linearity of magnetostriction causes a significant increase in vibration amplitudes. With a d.c. bias on the induction, the peaks in magnetostriction at the positive and negative peaks in flux density differ significantly; this is obvious from the magnetostriction loop of Figure 3.

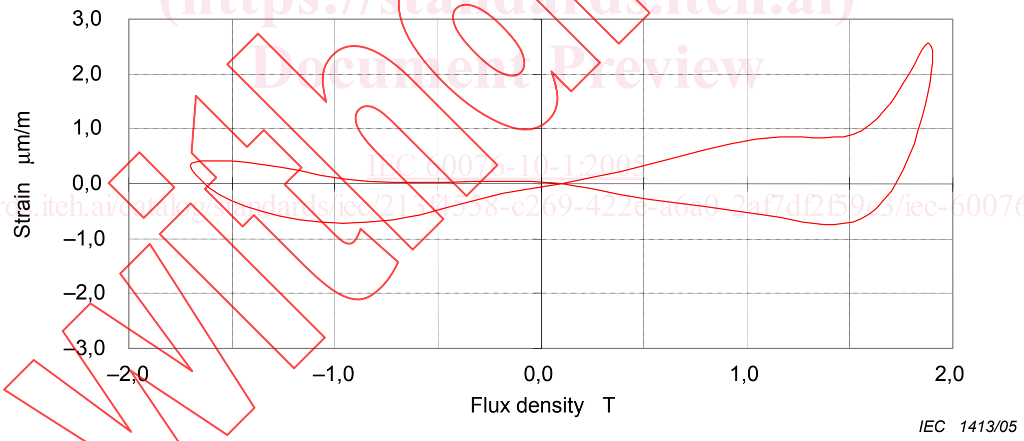


Figure 3 – Example curve showing relative change in lamination length during one complete cycle of applied a.c. induction with a small d.c. bias: 1,8 T, 50 Hz and 0,1 T, 0 Hz

The vibration pattern is repeated every 360°, that is every 20 ms in a 50 Hz system, indicating a magnetostriction at 1 × the exciting frequency. See Figure 4. The presence of peaks in the spectrum at odd multiples of the exciting frequency, is a clear indication of d.c. bias in the induction.

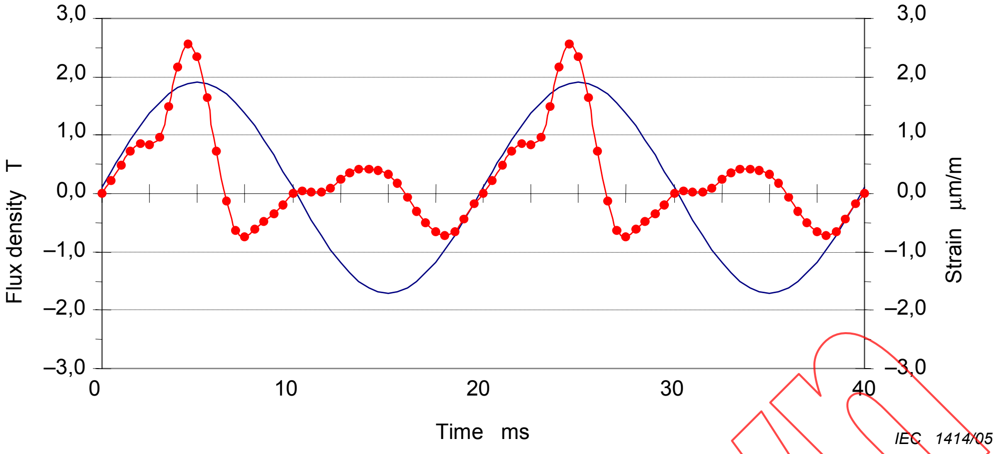
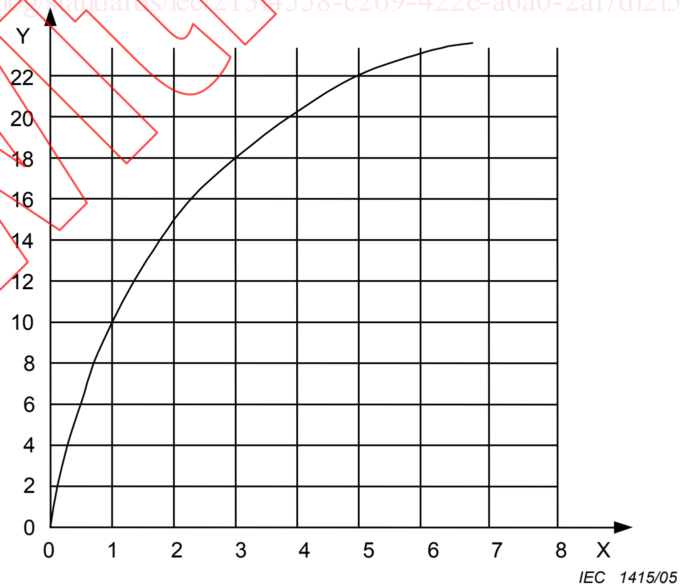


Figure 4 – Induction (smooth line) and relative change in lamination length (dotted) as a function of time due to applied a.c. induction with a small d.c. bias: 1,8 T, 50 Hz and 0,1 T, 0 Hz

Because of the possibility of d.c. bias magnetization affecting the true measurements, a transformer undergoing sound tests should be kept fully energised until the effects of inrush currents and remanence have died away and the sound levels have stabilised before making measurements. If residual d.c. magnetization is present, the sound level may be affected for a few minutes or, in extreme cases, for several hours.

The ratio between the d.c. bias current and the no-load current is an important parameter in determining the expected increase in sound power caused by the d.c. bias current. The relationship between d.c. bias current and sound level increase has been measured on a number of large power transformers; Figure 5 shows one set of this data.



Key

X axis d.c. bias current as per unit of a.c. no-load current

Y axis increase in total sound level in dB(A)

Figure 5 – Sound level increase with d.c. current in the windings