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Acoustics – Guide to the measurement of airborne acoustical noise and evaluation of its effects on man

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FOREWORD

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Acoustics – Guide to the measurement of airborne acoustical noise and evaluation of its effects on man

0 INTRODUCTION

The problems associated with the measurement of noise and evaluation of its effects are of increasing importance to the community, not only to specialists in acoustics, but also to a large number of individuals with more limited experience in this field.

Although noise-measuring equipment in common use is relatively simple to operate, a programme of noise measurements and the evaluation of the results obtained must be carefully planned. The correct methods, scales and units must be chosen and a number of precautions must be observed in order that meaningful results may be obtained.

This International Standard outlines some of the basic problems associated with the measurement of noise and evaluation of its effects on man and presents a summary of the methods in common use.

1 SCOPE AND FIELD OF APPLICATION

This International Standard describes the general procedures for the measurement of noise and evaluation of its effects on man.

It is intended as an introduction to the more specialized instructions contained in acoustical test codes and interpretation procedures published by national and international standardization bodies.

2 CLASSIFICATION OF NOISE PROBLEMS

2.1 Most noise problems may be classified as follows :

2.1.1 Problems associated with the determination of the amount and character of noise emitted by one or more noise sources, or with the prediction of the performance of one or more noise sources under specified conditions.

For problems of this group, the purpose of the noise measurements is to determine some physical quantity, usually the sound pressure level at a certain point or the sound power level of the source(s). The character of the noise may be described by the frequency spectrum and dependence on time of these levels and by the character of the sound field.

2.1.2 Problems associated with the evaluation and prediction of the different effects of noise on man.

For problems of this group, the purpose of the noise measurements is to obtain a quantity that relates the magnitude of the sound stimulus to the effects of the noise on man.

2.2 Broadly speaking, the problems of 2.1.1 are mainly concerned with the generation and transmission of noise, whereas the problems of 2.1.2 are mainly concerned with the reception of noise. It must be emphasized that these two categories are not mutually exclusive, because a particular noise problem is usually related to both categories. For example, the purpose of many noise abatement projects is to reduce the noise emitted by a source to a level at which the influence on man of the noise received is tolerable.

3 CLASSIFICATION OF DIFFERENT KINDS OF NOISE

The character of a noise may be described by its frequency spectrum, the variations of level with time, and the character of the sound field. Many noises have a continuous spectrum, i.e. the sound energy is rather evenly distributed over a large part of the audible frequency range. In some cases, discrete tones are clearly audible in the noise.

The noises most frequently encountered in practice may be classified according to the following characteristic features :

3.1 Frequency spectrum

3.1.1 *Continuous spectrum*

3.1.2 *Spectrum with audible discrete tones*

3.2 Dependence on time

3.2.1 *Steady noise :* A noise with negligibly small fluctuations of level within the period of observation.

3.2.2 *Non-steady noise :* A noise whose level shifts significantly during the period of observation.

3.2.2.1 *Fluctuating noise :* A noise whose level varies continuously and to an appreciable extent during the period of observation.

3.2.2.2 *Intermittent noise :* A noise whose level suddenly drops to the ambient level several times during the period of observation, the time during which the level remains at a constant value different from that of the ambient being of the order of magnitude of 1 s or more.

3.2.2.3 *Impulsive noise :* A noise consisting of one or more bursts of sound energy each of a duration less than about 1 s.

3.2.2.3.1 *Quasi-steady impulsive noise :* A series of noise bursts of comparable amplitude with intervals shorter than 0,2 s between the individual bursts.

3.2.2.3.2 *An isolated burst of sound energy :* The envelope waveform of the burst may be of constant or nearly constant amplitude, or it may be that of a decaying transient.

3.3 Character of sound field

3.3.1 *Free field :* The sound field in an area far from reflecting surfaces.

3.3.2 *Reverberant field :* That portion of the sound field in the test room over which the influence of sound received directly from the source is negligible.

3.3.3 *Semi-reverberant field :* The sound field prevailing in a large enclosure with moderately reflecting surfaces.

3.3.4 *Hemispherically divergent field :* The sound field of a source which is situated near to a hard reflecting plane (usually the ground) but free from other obstructions.

4 PHYSICAL MEASUREMENTS OF NOISE

The method of measurement must be chosen according to

a) the character of the noise problem (see section 2);

b) the character of the noise (see section 3) and the source;

c) the required degree of thoroughness of the description of the noise problem.

4.1 Noise problems of 2.1.1

The general problem is to determine the characteristics of the noise source and the noise emitted by the source.

4.1.1 *Quantities to be measured*

For the solution of problems in this group, the sound pressure level (expressed in dB re 20 $\mu N/m^2$) is measured as a function of time.

The sound pressure level may be measured in a broad frequency band covering the whole of the audible frequency range or, alternatively, in narrow **frequency bands.** The width of these bands may be 1/1 or 1/3 octave or narrower.

The term "band pressure level" is used to describe the sound pressure level measured in a particular band.

The measurement may also be made with a specified **weighting network** inserted in the measuring chain. The reading is then termed **sound level.**

NOTE — Weighting networks A and B (as defined in IEC Publications 123[14] and 179[15] and weighting network D[16] are used. The readings are then termed A-weighted, B-weighted sound level etc. and are expressed in decibels, commonly called dB (A), dB (B) etc.

4.1.2 *Choice of measuring methods*

The choice of measuring method depends on the type of sound source and its environment, the character of the noise and the degree of thoroughness needed in the description.

4.1.2.1 Source and environment

The ISO publications on noise measurements (see Bibliography) contain information on the appropriate choice of measuring methods, measuring points, corrections for background noise and investigation of acoustic environments for specific noise sources and environments, for example, machines[1] [2] [3], rotating electrical machinery[4], vehicles[6], and aircraft[7].

The measuring positions are chosen so that significant influence from small irregularities of the shape of the source or from the presence of other objects or sources is avoided. If these interferences cannot be eliminated, their influence on the result must be determined.

4.1.2.2 Character of the noise

In section 3, noises are listed according to their character in an order corresponding to the ease with which the noise measurements may be carried out. The procedures for measuring steady noise are well established and relatively simple. The methods for measuring impulsive noise are much more complicated and less well established.

4.1.2.3 Thoroughness of description

A thorough analysis of a noise problem requires recordings of band pressure levels in narrow frequency bands measured at suitable microphone locations over an appropriate time interval. For some problems, such a thorough description may be unnecessary. In such cases, a simplified measuring procedure may be entirely adequate for the purpose of the measurements.

The method to be selected depends upon the thoroughness of the description required for the particular noise problem under investigation.

4.1.3 *Methods available*

4.1.3.1 The survey method

This method requires the least amount of time and equipment. It may be used for comparisons between noise sources of similar characteristics. The sound field is described by the sound level as measured by a sound level meter. A limited number of measuring points is used and no detailed analysis of the acoustic environment is made. However, the time dependence of the noise being measured must be noted.

Readings of the sound level meter give the sound pressure level weighted according to a standardized frequency-response curve. In these cases, the use of A or C weighting networks is recommended although the use of other networks such as "linear" may be appropriate. For many practical cases, sound level C is a fair approximation to the overall sound pressure level. The A-weighted sound level is useful for assessments of human response (see section 5).

The minimum requirements to the specifications of the sound level meter are given in IEC Publication 123[14].

For greater precision, the sound level meter shall be in accordance with IEC Publication 179[15].

This method is generally of limited value if corrective measures to reduce the noise are to be evaluated. It is not suitable for the measurement of impulsive noise.

4.1.3.2 The engineering method

In this method, the measurements of sound level or sound pressure level are supplemented by measurements of band pressure levels. The acoustic environment is analyzed to determine its effect upon the measurements. The measuring points and the frequency range are selected according to the characteristics of the noise source and the environment in which it operates. The time dependence of the level during the period of observation may be recorded. The specifications of the measuring instruments shall conform with IEC Publications 179[15] and 225[17], where applicable.

The engineering method provides information that is usually sufficient for taking engineering action in many situations, for example, in connection with noise abatement programmes. It is not suitable for the measurement of impulsive noise.

4.1.3.3 The precision method

This method gives as thorough a description of the noise problem as possible.

The measurements of sound presssure level or sound level are supplemented by measurements of band pressure levels. Records are made over an appropriate time interval in accordance with the duration and fluctuations of the noise. The acoustic environment is carefully analyzed and the measuring points and the frequency range are selected according to the characteristics of the noise source and environment. If possible, the effect of the environment on the measurements is quantified by carrying out the measurements under laboratory-controlled conditions, for example, in a free-field or reverberation room.

Use of the precision method is required in complex situations where a thorough description of the noise field is needed.

The instruments used should preferably be in accordance with IEC Publication 179[15] and 225[17], but some problems, for example, in connection with the measurement of impulsive noise, may make the use of instruments with other specifications necessary.

4.1.4 *Presentation of results*

From measurements made by the survey method, it is possible to calculate a mean sound level. Instructions for this calculation are to be found in ISO/R 1680[4].

From measurements made by the engineering and precision methods, it is possible to calculate a mean level of the noise either in broad or narrow frequency bands. If the environment is suitable, it is also possible to calculate the sound power level of the source and a measure of its directivity. Instructions for performing the calculations are given in ISO/R 495[1], ISO/R 1680[4], ISO 2880[2] and ISO 2946[3].

It is possible to evaluate the time distribution function of the levels of fluctuating and intermittent noise. In some cases, this function can be used for the computation of the level of a steady noise having the same effect as the noise under test. Instructions for performing the calculations are given in ISO/R 1996[12] and ISO/R 1999[13].

From measurements made by the precision method, it is furthermore possible to evaluate the properties of impulsive noise and to make precise evaluations of the sound power level of the source[2] [3] and to determine its directivity etc.

When data obtained from measurements made according to this guide are intercompared or compared with other acoustical data, care shall be exercised to ensure the validity of the comparison in all respects. This precaution is necessary when the comparison is with other measured values or with prescribed values.

4.2 Noise problems of 2.1.2

The general problem is to determine the effects of noise on people. These effects cannot be measured directly with currently available physical instruments, but the methods mentioned in 4.1.3 can be used to collect information from which approximate measures of noise on human beings can be obtained as described in section 5.

5 EVALUATION OF THE EFFECTS OF NOISE ON HUMAN BEINGS

5.1 Quantities to be determined

Among the quantities describing the effect of noise on human beings are

a) the loudness level of the noise;

b) the perceived noise level of the noise;

c) the risk of damage to the hearing mechanism caused by the noise;

d) the degree of annoyance and interference with human activities (for example, speech communications, work, rest or sleep) caused by the noise.

5.2 Methods of determination of the effects

The psychophysical quantities characterizing the effects cannot be measured directly with currently available instrumentation.

The best solution would be to present the noise to a sufficiently large and representatively selected group of persons placed in exactly the same physical, psychological and social situation as the people on whom the influence of the noise should be predicted. By observing the responses of the members of this group, it is possible to extract information on the effects of the noise in question. This is, however, a very cumbersome and time-consuming method which can only be used in very special situations where information of a fundamental nature is required.

These subjective measurements may, however, be replaced by objective measurements when it is possible to relate some physical properties of the noise to a scale for rating subjective effects. This would generally only be possible if a thorough knowledge of the influence of many physiological, psychological and social factors on the effect of noise on human beings were at hand. It must, however, be emphasized that present knowledge of the effect on man is very limited. "Conversion methods" relating physical properties of noise to subjective effects are available only in special cases. Some of the conversion methods commonly used are described below. The basis information is obtained by objective measurements as described in 4.1.3 and 4.1.4.

Generally, results obtained by the survey method are of limited value for the evaluation of the effects of noise on man. In many cases, a knowledge of the spectral distribution of the noise energy is needed, i.e. the engineering or precision method must be used. In other cases, the supplementary information needed on the noise situation (distribution of levels of fluctuating noise, duration and repetition rate for intermittent and impulsive noise, character of background noise etc.) is only obtainable by the precision method.

5.3 Methods for relating physical properties of noise to an approximate measure of subjective effects

The conversion may be carried out by computation or by an electric network with specified characteristics included in the measuring instruments or by a combination of these methods. As a rule, the results are only valid in a limited range of situations for which the procedure is created. Even within this range they are generally of an approximate nature only.

5.3.1 *Loudness level and loudness*

The loudness level in phons of a sound signal is defined as the sound pressure level (re 2×10^{-5} N/m^2 = 20 μN/m^2) of a 1 kHz sinusoidal frontally presented tone subjectively judged to be equally as loud as the signal under test[18].

The loudness in sones is a numerical designation of the strength of a sound which is proportional to its subjective magnitude. One sone is the loudness of a sound whose loudness level is 40 phon[9].

Methods for approximate calculation of loudness level and loudness of steady noise are given in ISO/R 532[9].

The data needed for the calculation are the band pressure levels of the noise measured in 1/3 or 1/1 octave bands.

NOTE — The best agreement between the results obtained by calculation and those obtained by direct subjective measurements according to the definitions is obtained for steady noise signals having spectra without prominent narrow peaks. In some cases, discrepancies of several phons may be found between calculated values of loudness level and values measured according to the definition.

Data obtained by sound level measurements, especially with A-weighting network, have been found useful for rank-ordering of noises with respect to loudness level as long as the noises are of a similar character. It must be emphasized that the values measured are not those of loudness level, but should be termed A-weighted sound level and expressed in decibels, commonly called dB(A).

5.3.2 *Perceived noise level and noisiness*

The perceived noise level (PNL) of a sound signal in perceived noise decibels (PNdB) is defined as the sound pressure level (re 2×10^{-5} N/m^2 = 20 μN/m^2) of an octave band of frontally presented noise centred on 1 000 Hz subjectively judged to have the same perceived noisiness as the signal under test.

The noisiness in noys is a numerical designation proportional to the subjective magnitude of the nuisance of a noise. One noy is the perceived noisiness of a noise whose perceived noise level is 40 PNdB.

A method for the calculation of perceived noise level is given in ISO/R 507[7]. The method is developed to describe aircraft noise.

The data neeeded for the calculation of perceived noise level are the band pressure levels of the noise measured in 1/1 or 1/3 octave bands. The problem of establishing a better agreement between calculated and measured values of perceived noise level of aircraft is currently being considered by ISO. It is proposed to base the calculation on 1/3 octave band pressure levels and to include corrections for the presence of audible discrete tones and the duration of the overflight. The problem of establishing a simple method for direct, approximate measurement of perceived noise level of aircraft is also being considered by ISO. For this purpose, it is proposed to use a special weighting network in the measuring equipment (D-weighting)[16].

In most cases, A-weighted sound level may be used for the rank-ordering of noises with similar characteristics with respect to perceived noise level.

5.3.3 *Permissible (low-risk) noise exposures for hearing conservation*

The susceptibility to damage of the hearing mechanism caused by noise exposure varies considerably between individuals and cannot be predicted in each case. Therefore, permissible limits for noise-exposure must be set and used conservatively. The problem is considered in ISO/R 1999[13], which gives a procedure for the evaluation of the risk of hearing impairment from noise-exposure during the work. Information on the sound level A and duration of the noise and the exposure during a typical week is used to calculate the level of a steady noise considered to be equally hazardous to hearing.

5.3.4 *Annoyance caused by noise*

The problem of rating noise with respect to annoyance on the basis of physical measurements is so complicated that present-day knowledge allows only a very approximate solution. Some aspects of the problem are considered in ISO/R 1996[12], which provides a basis for the establishment of permissible limits for noises in various situations by the competent authorities.

The method described is valid for estimation of community response to noise both outside and inside residential premises, offices, business stores, restaurants and workshops, etc.

According to ISO/R 1996[12], steady noise without audible discrete tones is rated by the sound level A. For steady noise with audible discrete tones, fluctuating, intermittent noise and certain sorts of impulsive noises, the level of a steady noise (without audible discrete tone) which is assumed to cause the same community response as the noise under test is calculated and used for the rating.

Where corrective measures are required, it may be necessary to perform the rating of the noise by means of a set of noise rating curves (see ISO/R 1996[12] on the basis of measurements of band pressure levels.

5.3.5 *Interference with speech communication* caused by the noise may be estimated by calculating a factor called the articulation index. From this index, the speech intelligibility in the presence of the noise may be derived. The band pressure level of the noise as well as other information is required for the calculation. The detailed calculation procedure is described in the acoustic literature. The procedure is complicated and the best agreement between calculated and subjectively measured values is obtained for steady noise signals with broad band spectra.

A simpler method based on measurements of band pressure levels in the octaves centred on 500, 1 000 and 2 000 Hz is also used. The average of these band pressure levels is called the Speech Interference Level (SIL).

The problem is currently being considered by ISO in order to arrive at a simple procedure giving results of practical value.

5.4 General remarks on evaluation procedures

It is clear from this brief résumé that the complicated nature of the physiological, psychological and physical processes makes it impossible for a single, simple method to be applicable to all types of noise problems.

Under some conditions, the survey method will yield data of great value in assessing the effect of a noise stimulus on human beings.

The engineering and precision methods are, however, of far wider applicability. From the data obtained by using these methods, it is possible to calculate with reasonable accuracy some psychophysical quantities that are related to the effect of the noise on human beings.

This International Standard summarizes a number of the better-established usages concerning the measurements of noise and evaluation of its effects on man. It does not claim to cover all cases nor to include certain procedures which are in different jurisdictions. Although the methods described here are incomplete in some respects, they will be found useful in many practical cases where action such as setting limits for noise levels is required.

It is necessary that current and future research lead to refinements of these methods. To avoid unnecessary proliferation and duplication, it is strongly recommended that emphasis both in research and practice be placed on the methods described in this International Standard.

BIBLIOGRAPHY (International Standards, ISO Recommendations and IEC Publications concerning procedures and equipment for noise measurements)

Procedures for planning and carrying out noise measurements and for evaluation of results :

[1] ISO/R 495, *General requirements for the preparation of test codes for measuring the noise emitted by machines.*

[2] ISO 2880, *Acoustics – Determination of sound power emitted by small noise sources in reverberation rooms – Part I : Broad-band sound sources.* (At present at the stage of draft.)

[3] ISO 2946, *Acoustics – Determination of sound power emitted by small noise sources in reverberation rooms – Part II : Discrete-frequency and narrow-band sound sources.* (At present at the stage of draft.)

[4] ISO/R 1680, *Test code for the measurement of the airborne noise emitted by rotating electrical machinery.*

[5] ISO/R 2151, *Measurement of airborne sound emitted by compressors intended for outdoor use.*

[6] ISO/R 362, *Measurement of noise emitted by vehicles.*

[7] ISO/R 507, *Procedure for describing aircraft noise around an airport* (2nd edition, 1970).

[8] ISO/R 1761, *Monitoring aircraft noise around an airport.*

[9] ISO/R 532, *Method for calculating loudness level.*

[10] ISO/R 454, *Relation between sound pressure levels of narrow bands of noise in a diffuse field and in a frontally-incident free field for equal loudness.*

[11] ISO/R 226, *Normal equal-loudness contours for pure tones and normal threshold of hearing under free field listening conditions.*

[12] ISO/R 1996, *Acoustics – Assessment of noise with respect to community response.*

[13] ISO/R 1999, *Acoustics – Assessment of occupational noise exposure for hearing conservation purposes.*

Equipment for noise measurements :

[14] IEC Publication 123, *Recommendations for sound level meters.*

[15] IEC Publication 179, *Precision sound level meters.*

[16] A document concerning weighting network D, for the time being a working document of IEC/TC 29.

[17] IEC Publication 225, *Octave, half-octave and third-octave band filters intended for the analysis of sounds and vibrations.*

General :

[18] ISO/R 31/Part VII, *Quantities and units of acoustics.*

[19] IEC Publication 50(08), *International electrotechnical vocabulary – Electro-acoustics.*

[20] ISO/R 266, *Preferred frequencies for acoustical measurements.*

[21] ISO/R 131, *Expression of the physical and subjective magnitudes of sound or noise.*

[22] ISO/R 357, *Expression of the power and intensity levels of sound or noise.*

[23] ISO/R 1683, *Preferred reference quantities for acoustical levels.*

Copies of these International Standards, ISO Recommendations and IEC Publications may be obtained through the national standards organizations affiliated with the ISO (International Organization for Standardization) or the IEC (International Electrotechnical Commission).

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