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Specifications and testing strategies for measurement devices for noise exposure determination in the infrasound frequency range

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Abstract

This document compiles specifications and requirements with which measurement devices shall comply, when applied for noise exposure determination in the frequency range of 1 Hz to 20 Hz. It reviews available European standards and documents with respect to regulations about the measurement of infrasound and the IEC 61672-series of standards concerning requirements of sound level meters. Beginning with these results, the necessary specifications for sound level meters that should be applied in the infrasound frequency range are discussed. Because of the specific properties of sound in this frequency range, typical malfunctioning scenarios known from measurement and testing practice are considered. Specification lists for measuring instruments and requirements of testing facilities summarise the most important conclusions for further discussion.

1 Introduction

The emission of infrasound is increasing in commercial activities and everyday life. This leads to the situation that the traceable and reliable measurement of sound in this frequency range is of growing relevance. A very general and basic prerequisite of such a measurement is the availability of tested and approved devices fulfilling internationally accepted regulations and standards. Unfortunately, currently available international documents for sound level meters or sound measurement procedures do not cover the infrasound frequency range and national regulations or guidelines vary widely. Thus, the goal of this document is to propose requirements and specifications for sound measuring devices and their testing and type approval at low frequencies and infrasound.

The most important source for requirements on sound level meters (abbreviated as SLM in the following) is the international series of standards IEC 61672 [1-3]. In three parts it gives specifications on instruments, pattern evaluation tests and periodic tests. The first part defines acceptance limits and maximum-permitted uncertainties of measurements for a wide list of performance specifications and requirements on the influence of static pressure, air temperature, humidity, electrostatic discharge, EMC and mechanical vibration. These specifications are limited to the standard frequency range of conventional sound level meters from 10 Hz to 20 kHz. They form, however, the basis for extending the specifications and requirements on measurement devices for noise exposure determination into the infrasound frequency range between 1 Hz and 20 Hz.

Another source of potential input are national standards and related guidance documents from several European countries that refer to low frequency sound. These are the German standard DIN 45680 [4a, 4b], the Polish standard PN-N-01338 [7], the French standard XP S31-135 [12] and the Danish and UK documents [13, 14, 15]. An ongoing revision of the German standard DIN 45657 [5], which aims for additional infrasound requirements on SLMs, is not yet available at the time of this writing. Furthermore, experiences gathered during SLM type approval testing at PTB and periodic testing at other institutes are integrated. Wherever possible, limit values (as acceptance limits) and associated measurement uncertainties are given.

This document is split into three main sections. The first section discusses the performance specifications and requirements of infrasound level meter in detail. The main aspects of IEC 61672-1 are discussed and the differences and extensions for the treatment of infrasound are derived. In the second section, a list of specifications on instruments is given including aspects which seem to be necessary to fulfil the referenced standards and documents, in particular the requirements in national standards already in place. The third section presents a further list that states requirements on standard SLM facilities in order to extend necessary tests into the infrasound frequency range, kept separate for type approval testing, periodic testing and daily testing before measurement.

2 Performance specifications & requirements

General

Generally, the instrument shall have the potential to provide measurements in a frequency range that allows detection of low frequency and infrasound signals. This applies at least to the electrical high pass filtering of the instrument and to the acoustical high pass filtering introduced by the static pressure equalization mechanism built into the microphone.

The relevant national standards for measurement of infrasound refer to different frequency ranges. The lowest frequency range is the 1 Hz third-octave band, used by the French standard [12]. The Polish standard [7] defines infrasound within the range of 1 Hz to 20 Hz. The Danish documents goes down to 2 Hz for the measurement of infrasound and 1 Hz for calibration. In Germany, 1 Hz third-octave band is under discussion for extended measurements in infrasound range [4a]. Following this, the operating frequency range of an infrasound level meter should include the 1 Hz third-octave band.

In practice, the exact frequency limits of a SLMs detection range often are not properly defined by the manufacturer. That may lead to the situation that results yielded with two different SLMs are not comparable. It is therefore recommended to define a unique lower cut-off frequency for all infrasound level meters. In the case of an infrasound extension of a standard sound level meter, the recommendation applies to the infrasound measurement mode. Following the discussion above this frequency limit should be set at the lower limit of the third-octave band with a centre frequency of 1 Hz, according to the filter standard IEC 61260-1 [8] which is at about 0.89 Hz. The actual low frequency limit value needs to be stated in the device manual.

The vent, providing for static pressure equalization in a condenser microphone, is a small opening beside the membrane and it strongly affects the low frequency response of the microphone. Two related aspects have been observed to be important in practice: The vent of an infrasound microphone is very narrow and must be prevented from being clogged by any dirt. Secondly, when putting the microphone in a closed coupler for acoustical measurement, for example for acoustical calibration, then the vent has to be placed clearly inside or outside the coupler (i.e. either fully exposed or fully not exposed to the sound pressure in the coupler). Partial of ambiguous location of the vent during the measurement or calibration leads to indeterminate results. The manufacturer should consider these aspects by an appropriate design of device and calibration strategy and give necessary information in the manual.

Adjustment at the calibration check frequency

According to IEC 61672-1 [1], at least one model of a sound calibrator shall be defined for checking or adjusting the overall sensitivity of a SLM. The calibrator provides a standard sound pressure level at a calibration check frequency which is used to adjust the instrument and, first of all to prove its correct operation in the field. IEC 61672-1 sets the calibration check frequency of a standard SLM to be at any frequency in the range of 160 Hz to 1250 Hz, usually 1000 Hz is applied, less frequent 250 Hz.

Membrane defects are a common problem in practice. These are holes in the membrane, e.g. introduced by environmental influences, which strongly affect the infrasound sensitivity. In many cases they can neither be detected acoustically at one of the conventional calibration check frequencies nor by using an electroacoustic actuator [16]. This problem can only be solved by extending the calibration check frequency range to much lower frequencies and by making a daily acoustical low-frequency functionality check.

Ideally this should be accomplished at the lowest frequency involved in the measurement task by a type-approved sound calibrator operating at that frequency (which might be termed an infrasound calibrator). Since currently technology is not fully implemented to provide a versatile, stable, and easy-to-use calibrator, alternative methods should be taken into account. During periodic tests or a type approval acoustic test, however, use of an infrasound calibrator should be mandatory.

Directional response, corrections

The directional response is less critical as long as the instrument is geometrically small compared to the wavelength of the sound. This requirement is usually fulfilled since even large instruments for long-term automated outdoor usage have typical dimensions below 1 m. This is still 'small' compared to the shortest wavelength of about 17 m in the frequency range 1 Hz to 20 Hz.

Corrections to indicated levels due to reflection and diffraction are negligible due to the sensor size-wavelength relation. Windscreen corrections might apply in the same way as for audible sound depending on the screen.

Frequency weighting and band filtering

Frequency weightings allow signal filtering to include human hearing properties into a compact noise assessment. The most often used A-weighting and C-weighting show very high attenuation below 10 Hz (e.g. the A-weighting attenuation factor is -148.6 dB at 1 Hz) which restricts their usability for infrasound. The Z-weighting (linear weighting, no attenuation) is used instead, e.g. in [4a]. The Polish standard [7] for the assessment of infrasound noise at working places makes use of the G-weighted equivalent sound pressure level referred to an 8-hours-working day and to a working week. G-weighting is also used in Denmark [13, 14]. It is defined in [6] and provides determination of weighted sound pressure levels of sound or noise whose spectrum lies partly or completely within the frequency band from 1 Hz to 20 Hz.

A-, C- and Z-weightings are defined in IEC 61672-1 [1] but the wide acceptance limits below 20 Hz make these definitions only useful in the audible frequency range. Narrower acceptance limits have to be defined at infrasound frequencies for these to be useful. The acceptance limits of [-1 dB; +1 dB] that IEC 61672-1 gives for audible frequencies may be used for infrasound frequencies too. The French standard XP S31-135 [12] gives [-3 dB; +3 dB] for 1 Hz to 16 Hz. It must be noted, however, that determination of very high attenuation values during testing is a challenging task.

In earlier versions of some standards, such as the current version of DIN 45680 [4b], the difference between C-weighted and A-weighted values, sometimes called (C-A)-weighting, is used to detect a potential low frequency signal component, since C-weighting has significantly less attenuation in the low-frequency region. This is a simple and effective way to detect the presence of a low frequency signal using the functionality already implemented within an instrument. Note that high level uncertainties due to the large attenuation values at very low frequencies, occur during determination of these variable. Nevertheless, it is used in current standards, which requires as a consequence, that A-weightings and C-weightings are defined even at infrasound frequencies.

Beyond the current scope of the sound level meter standards in the IEC 61672-series, quantities defined in third-octave bands or similar band filters may be used, as in the current draft of the revision of DIN 45680 [4a]. In that case, filter tests according to the filter standard IEC 61260-2 [9] must be performed during a type approval.

Level linearity

IEC 61672-1 [1] requires the measured signal level to be a linear function of the sound pressure level at the microphone for the entire extent of the total range of a device. This requirement should also hold at infrasound frequencies. It is recommended to perform the level linearity tests acoustically down to the 1 Hz third-octave band for both type approval and periodic testing including all frequency weightings. If this is not possible, the lowest test-frequency requirement should be given in the manual.

Self-generated noise

The self-generated noise has to be declared in infrasound frequency range. It strongly depends on the effective bandwidth of the detection frequency range. Thus, if several frequency ranges are selectable, such as a standard frequency range and an extended low-frequency range, the requirement applies to each setting.

Time weightings, time averaging and peak levels

The standard Fast or Slow time weightings are often used in the audio frequency range, but their respective time constants of 0.125 s and 1 s are comparable to a low frequency acoustic period and are therefore not appropriate for infrasound applications. Especially when using Fast weighting, results may be observed to follow the instantaneous sound pressure leading to strange effects. Time weightings should not be applied to sound signals dominated by frequency components of equal or less than 3 times the inverse value of the time constant, leading to a limit of 3 Hz for Slow weighting and a limit of 24 Hz for Fast weighting.

The authors have not found evidence of time weightings with longer time constants being used. Instead, energy equivalent linear averaging (equivalent sound pressure level L_{eq}) within particular but limited time intervals is used, e.g. by [7] and [12].

For all measurements, the measurement time interval must include at least several periods of the sound signal. In the UK, L_{eq} measurement over 5 minutes is suggested for low frequency sound. L_{eq} measurement over 30 s are required in France [12]. In general, the measurement time depends on the dominant signal components and should, in any case, cover the main emission times of the source. No result should be displayed by the instrument before the end of that minimum measurement time.

Toneburst response

Tonebursts occur also at infrasound frequencies. For example, the opening of a door to a closed room leads to a burst with an instantaneous sound pressure amplitude in the range of about 10 Pa. IEC 61672-1 [1] defines a number of requirements for instrument response to single and repeated tonebursts. A reference toneburst of 4 kHz is used for specification with different toneburst durations from 0.25 ms (1 period at 4 kHz) to 1 s. The related test which is based on the reference burst of 4 kHz and which is formulated in Part 2 [2] should be able to uncover any defects of burst detection at infrasound frequencies. Additional requirements and tests do not seem necessary.

Overload and under-range indication, Long-term stability, high-level stability, reset, thresholds, display, timing facilities, cross talk, power supply

No special requirements seem to be necessary here. The timing facilities and, for example battery lifetime, should be appropriate even for long duration infrasound measurements.

Environmental requirements

The requirements on stability against environmental conditions (air temperature, static pressure, humidity), electrostatic discharge, EMC and mechanical vibrations have also to be considered at infrasound frequencies. It can, however, be expected that similar relations are valid as known from audible sound measurements. These can be adopted from IEC 61672-1 [1].

Condenser microphones are sensitive to changes in atmospheric temperature, humidity and static pressure. This is usually accounted for in the microphone's datasheet by a temperature or pressure coefficient valid at 250 Hz. The environmental coefficients of a microphone should have values within a defined range in order to pass the testing for environmental influence of IEC 61672-2 [2].

In general, the environmental behaviour of condenser microphones can be expected to be similar to those in the audible frequency range. According to [10] and [11], especially the pressure coefficient of microphones may change to low frequencies, depending on the cartridge type. It is expected that this holds for the temperature coefficient, too. Therefore, it is recommended to examine typical pressure and temperature coefficients of working standard microphones below 10 Hz. Depending on the results, specific infrasound limits to environmental influence have to be derived. Finally, this will require an appropriate test procedure and equipment equivalent to IEC 61672-2, such as a infrasound calibrator.

It should be mentioned here that, when testing a sound level meter equipped with an infrasound microphone for static-pressure response according to IEC 61672-2 [2], a better sealing of the pressure chamber is required compared to testing standard microphones. Due to the low cut-off frequency of infrasound microphones, reliable measurements take much more time. Even slight leakage leads to incorrect measurements and to a possible false failing of the device under test.

Detection of microphone membrane defects

A potential problem in low-frequency measurements are perforations in the microphone diaphragm. These may happen due to dirt, corrosion, aggressive or hot measurement environments, or mistreatment of the microphone. A perforated diaphragm allows low frequency sound pressure to pass through the diaphragm rather than displace it, thus bypassing the transduction mechanism. This tendency reduces as the frequency increases resulting in an unexpected high-pass response depending on the size of the perforation. Small defects cannot be seen by eye and don't have any appreciable effect on measurements in the audible frequency range. They are thus not detected by a routine check with a sound calibrator at 250 Hz or 1 kHz, or a full calibration that does not extend into the low frequency region.

This issue should be addressed at periodic testing and it could be valuable to perform a daily check at low frequencies, too. Testing practice shows that optical inspection (using a microscope or the transmitted-light method) cannot reliably detect defects. It is not able to detect defects by the electroacoustic actuator method [16]. Acoustical testing showing the frequency response at infrasound frequencies is required.

As discussed above, ideally routine checking with each use of the SLM should be accomplished at the lowest frequency involved in the measurement task by a type-approved infrasound calibrator. Since current technology is not fully implemented to provide a versatile, stable and easy-to-use infrasound calibrator, the development of such a device should be considered.

3 List of instrument performance specifications

The following list summarises the proposed specifications and requirements which should be applied in extension to the specifications of the IEC 61672-series if a SLM is approved and applied in the infrasound frequency range:

- The lower frequency limit of the detection range shall be declared in the manual as the -1 dB-cut-off frequency. For infrasound measurements the detection range shall include at least the 1 Hz third-octave band as defined by IEC 61260-1 [8].

- The deviation of the implemented Z-weighting from nominal value shall be within narrow acceptance limits at low-frequencies (from [-1 dB; +1 dB] at 16 Hz to [-3 dB; +2 dB] at 1 Hz). This also applies to A-, C- and combined (C-A)-weighting. The attenuation values of the A-, C- and Z- weightings are defined as functions of frequency in IEC 61672-1 [1].

- If implemented, G-weighting shall be within the acceptance limits of ISO 7196 [6].

- If implemented, fractional-octave band filtering (including the common third-octave band filtering) shall be within the acceptance limits of IEC 61260-1 [8].

- Level linearity at infrasound frequencies shall be within the same acceptance limits as for conventional frequencies according to IEC 61672-1 [1]. The Instruction Manual shall state the lowest frequency for which level linearity was verified during type approval testing.

- Minimum detectable sound levels at infrasound frequencies shall be stated in the manual for all implemented measurement quantities and all implemented frequency ranges.

- Time-weightings shall be applied only at sufficient high frequency (F at frequencies >24 Hz, S at frequencies >3 Hz).

- The SLM shall allow long-term measurement adapted to the long periods of infrasound. Results shall not be displayed before a sufficiently number of signal periods have been measured.

Furthermore, the following issue might be relevant according to ongoing discussions.

- The Instruction Manual shall state a method for a routine acoustical function check of the SLM. The development of an easy-to-use infrasound calibrator is recommended.

4 List of tests

The following issues are stated as infrasound related extension of the standard SLM testing as defined in IEC 61672-2 [2] for type approval testing, in IEC 61672-3 [3] for periodic testing and in IEC 61672-1 [1] for routine acoustical function checking.

Type approval testing

- Apply acoustical testing of all relevant frequency weightings (Z, A, C, (C-A), G) down to the lower limit of the 1 Hz third-octave band.

- Extend electrical testing of frequency weightings A, C, Z and (C-A) down to the lower limit of the 1 Hz third-octave band.

- If applicable, add electrical testing of G-weighting according to ISO 7196 [6].

- If applicable, add band filter testing down to the 1 Hz third-octave band according to IEC 61260-2 [2].

- For level linearity testing according to IEC 61672-2 [2] at infrasound frequencies add a test point at 2 Hz. The test shall be performed acoustically.

- Extend the low noise testing to infrasound frequencies down to the lower limit of the 1 Hz third-octave band.

- Introduce the checking of appropriate minimum measurement times and appropriate usage of time weightings.

- Assure that static-pressure-testing chamber is properly sealed for the testing of infrasound microphones according to IEC 61672-2 [2].

If relevant, also the testing of infrasound calibrators and the testing of additional time weightings must be implemented.

Periodic testing

- Extend acoustical testing to low frequencies (< 10 Hz) to detect microphone diaphragm defects.

- Extend electrical testing to the lower limit of the 1 Hz third-octave band.

If relevant, test infrasound calibrator acoustically.

Routine testing by user

- Before measurement, check the microphone vent for any dirt or defects.

If relevant, perform a functional check of the infrasound SLM using an infrasound calibrator.

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