Sound properties

Sound is a mechanical (acoustic) wave propagating through an elastic medium. It is defined by the conventional frequency range of the human ear, i.e. 16 Hz–20 kHz. Acoustic waves with a lower frequency are called infrasound, and with a higher frequency ultrasound.

Physical acoustics deals with the laws of acoustic wave propagation, including their mathematical description and technical applications. Very roughly, physical acoustics deals with behavior that can be described using data such as frequency or intensity.

Physiological acoustics', on the other hand, deals more with hearing and speech from a physical point of view, but taking into account the properties of auditory receptors and physiological effects. Physiological acoustics deals, for example, with the study of the threshold of sensitivity, the threshold of pain or the perception of the color of tones, it introduces new quantities such as the level of intensity in particular.

Physical Properties

Frequency

Frequency indicates the number of oscillations per second. It indicates the pitch in the audible range. Its inverse value is the period, it indicates the duration of one oscillation.

Speed of sound wave propagation

The general relationship applies to the propagation speed of acoustic waves in a general environment:

$$c = \sqrt{\frac{K}{\rho}}$$

where K is the bulk modulus of the medium and ρ is the density of the medium.

The following applies to the propagation speed of acoustic waves in gases:

$$c = \sqrt{\frac{\kappa p}{\rho}}$$

where κ is Poisson's constant, ρ is gas density, p is gas pressure

To illustrate, the speed of sound ranges from about ``330 m/s *in air (strongly temperature dependent), through ``1450 m/s* in fat and ``1570 m/s *in blood to ' '4080 m/s* in skull bones.

Wavelength

The wave propagates through the medium at a finite speed. The wavelength is actually the distance between the two maxima. It is related to the speed of the wave and to the frequency:

$$\lambda = \frac{c}{f}$$

The inverse of wavelength, the ``wavenumber *(expressing how many waves fit into 1 m) is sometimes used, but this is not common in acoustics.*

Acoustic speed

Since sound is a mechanical oscillation of particles around an equilibrium position, they oscillate with some speed ``v*.*

Sound pressure

The propagation of the wave in the environment creates places with dilution or particle crowding. Macroscopically, this manifests itself as pressure fluctuations. The magnitude of the sound pressure depends, among other things, on the density of the medium, the speed of the wave and the frequency of the wave.

With the acoustic velocity v, the acoustic pressure p is connected by the acoustic impedance quantity Z, which is a characteristic of the environment:

$$Z = \frac{p}{v}$$

As a result, the acoustic pressure is understandably superimposed on the atmospheric pressure.

The maximum acoustic pressure p_{MAX} is difficult to measure, therefore, in practice, similarly to e.g. in electrical engineering, the value of the effective pressure is used. The introduction of the rms value is related to the energy transferred and the mathematical derivation, while not complicated, is beyond the needs of medical students. For harmonic waves:

$$p_{EF} = \frac{\sqrt{2}}{2} p_{MAX}$$

Once again, it should be emphasized that this only applies to harmonic waveforms. In the case of a non-harmonic waveform, it depends on the specific meter, sometimes the value can be correct, but especially with older or poorly designed instruments it can be highly misleading.

For other needs, the **threshold sound pressure** p_0, is defined as a somewhat conventional value of the sound pressure that the human ear can still hear when using a pure tone of frequency *1 kHz* yet to register:

$$p_0 = 2 \cdot 10^{-5}\ Pa$$

Ripple intensity

Wave (sound) intensity is defined as the amount of energy that passes through a unit area perpendicular to the direction of propagation per unit time.

Similar to the acoustic pressure, the threshold intensity I_0 is also introduced for the wave intensity as the lowest yet registrable intensity of a pure tone with a frequency of *1 kHz*:

$$I_0 = 10^{-12}\ W \cdot m^{-2}$$

Sound intensity level

Since the intensity of common sounds fluctuates in the range of several decades, a logarithmic scale is introduced, which assigns a zero value to the threshold intensity:

$$L = 10 \cdot \log \frac{I}{I_0}$$

The intensity level is based on the ratio of two equal quantities and is therefore dimensionless in SI. The unit decibel (dB) is used to indicate the levels defined in this way (not only in acoustics, but also, for example, in electrical engineering). The unit is named after the Scottish scientist and inventor of the first practically usable telephone A.G. Bell, the prefix deci- means multiplying by ten.

Since the wave intensity is directly proportional to the square of the sound pressure, the following also applies:

$$L = 20 \cdot \log \frac{p}{p_0}$$

Physiological properties

Acoustic spectrum

In the general case, the acoustic signal does not consist of a single tone with a harmonic (“sine”) waveform, but the waveform has a more complex shape. If this course is periodic, we perceive it as a pure tone. Decompose the pure tone into the sum of possibly differently shifted sine waveforms with frequencies f_0, $2f_0$=f_1, $3f_0f_2$,... (Fourier's theorem). Plotting the amplitudes of these sine waves represents the amplitude spectrum of the acoustic signal. Such a spectrum is called discrete because it consists of only discrete points. The fundamental frequency f_0 determines the pitch. Other frequencies f_1,... are called higher harmonics, they determine the color of the tone.

If the sound is not periodic, that is, if it is a one-time event like an explosion or a consonant, or if it is noise, it can be viewed as a periodic event with an infinitesimal period and therefore an infinitesimal frequency. The spectrum of such a non-periodic signal is then continuous.

Volume

Since the relationship between the intensity of the wave and the intensity of the sensation depends, among other things, on the frequency, the relationship must be evaluated individually for each frequency (pitch) of the tone. Volume and volume level are used for comparison, which quantify any differences in perceived intensity.

The loudness level '**L_N** *is defined by comparison with the intensity level at the frequency of* 1 kHz*. A tone at any frequency has exactly the same loudness level as a tone with a frequency of ``1 kHz*, which we perceive as equally strong. The volume level unit is *phone (Ph)*.

Loudness '**N**' was defined because loudness level does not quantify perceptual differences very well. The reference point is a tone with an intensity level of *40 dB* at a frequency of *1 kHz*, which is assigned the value of *1*. The unit of volume is *son*. The volume can be determined from the volume level according to the following relationship:

$$N = 2^{\frac{L_N - 40}{10}}$$

In fact, the perceived intensity also depends on whether a truly pure tone is used. When measuring the volume of sounds that do not have a sinusoidal course (one-point spectrum), the frequency dependence of the individual components must also be taken into account. A common approach is to connect a frequency filter, which suppresses unperceived components in the measured signal in a precisely defined manner and limits the influence of individual frequencies.

Links

Resources

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- SCHAUER, Paul. *Selected states from acoustics* [online]. Department of Physics, Faculty of Civil Engineering, BUT Brno, [cit. 2013-08-20]. <http://fyzika.fce.vutbr.cz/doc/vyuka_schauer/vybrane_state_z_akustiky.pdf>.

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