

Properties of Sound

Sound is a mechanical (acoustical) wave which propagates through a medium such as air, water and solids. It is bounded by the conventional frequency range of human ear, spreading from 16 Hz to 20 kHz. Acoustical wave with lower frequency is called infrasound, with higher ultrasound.

Physical acoustics studies the propagation of acoustical wave, including mathematical equations describing it.

Physiological acoustics studies mainly hearing and speech from physical aspect while considering physiological effects and properties of hearing receptors.

Physical properties

Frequency

Frequency is the number of occurrences of a repeating event per unit of time. In case of sound it defines the pitch. Its reciprocal value is called period and shows duration of one repetition.

Wave propagation velocity

Following general equation can be used for the velocity:

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

where K is the bulk modulus (of volumetric elasticity), ρ is gas density, p is gas pressure.

For example, velocity differs in air approximately 330 m/s, in fat 1450 m/s, in blood 1570 m/s and in cranial bones 4080 m/s.

Wavelength

The wave propagates with finite speed. The wavelength is distance over which the periodical wave repeats. The equation is as follows:

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

Sometimes *wavenumber* is used instead. It is reciprocal value of the wavelength indicating how many waves can fit into 1 m.

Acoustical velocity

Since sound is mechanical wave, the particles oscillates around their mechanical equilibrium with velocity v .

Sound pressure

Propagation of the wave is created by over time changing density of particles. In macroscopical aspect it can be seen as varying pressure. Size of the sound pressure depends on density of the environment, velocity of the wave and frequency of the wave.

Acoustic impedance Z is quantity representing one of the characteristics of the environment. It is dependant on the sound pressure and sound velocity:

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

The maximal sound pressure p_{MAX} is hardly obtained, thus the effective value of the pressure is used instead. The effective value is associated the energy transfer. For harmonic wave following equation is used:

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

This equation is for harmonic oscillations only, for non-harmonic other methods are used, however they are very often unreliable.

For next use, another quantity is defined and it is **reference sound pressure** p_0 , which is the lowest value of the pressure that can be heard by human ear at frequency 1 kHz . The equation is:

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

Sound intensity

Sound (acoustic) intensity is defined as is defined as the power carried by sound waves per unit area in a direction perpendicular to that area.

Again the reference sound intensity I_0 is defined as the lowest sound intensity that can be registered by the human ear at frequency 1 kHz :

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

Sound pressure level

Because sound intensity of common sounds can vary over many decades, the logarithmic scale is defined. The zero value is associated to the reference sound intensity:

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

Since it is calculated from two values with the same unit it is dimensionless quantity in the SI. In acoustics the decibel unit is used (dB). It is named in honor of A. G. Bell, who was Scottish scientist and inventor of first practically usable phone.

Since the intensity is proportional to the square of the sound pressure, this equation is valid at the same time:

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

Physiological properties

Sound spectrum

Generally the wave of the sound has not just sinusoidal shape, it is somehow more complex. When the wave is periodical, perceived sound is heard as a pure tone. This tone can be unfolded into individual sinusoidal shaped waves that are shifted in time from others. It can be achieved with Fourier transform. Taking out the amplitudes of individual waves creates the sound spectrum. The sound spectrum is discrete. Always there is one fundamental frequency f_0 and other waves are called higher-harmonic frequencies ($f_1=2f_0$, $f_2=3f_0$, etc.). Fundamental frequency f_0 defines pitch of the tone, higher-harmonic frequencies define the timbre of the sound.

If the sound is not periodic, it is perceived for example explosion, scratching, consonants, or noise. This sound can be considered as periodical action with finite period.

Loudness

Since relation between sound intensity and feeling intensity depends on the frequency, the relation must also depend on the frequency. For comparison loudness and loudness level are used.

Loudness level L_N is defined using comparison to the intensity level at 1 kHz . Tone at any frequency has the loudness level as the tone at 1 kHz , which we perceive as at the same level. Unit of loudness level is *phon* (Ph).

Because quantifying loudness level is quite hard, the quantity **loudness** N was defined. The reference tone with value 1 is tone at intensity level 40 dB and frequency 1 kHz . Unit for the loudness is *sone*. Loudness can be calculated using following equation:

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

In real life, the perceived intensity depends on the tone, whether is pure or not. When measuring loudness of sounds without sinusoidal wave, the frequency dependency of individual components should be taken into account. In praxis the frequency filter (which suppresses defined frequencies) can be used.

Links

External links

- KUBATOVA, Senta. *Biofot* [online]. [cit. 2011-01-31]. <<https://uloz.to/!CM6zAi6z/biofot-doc>>.
- SCHAUER, Pavel. *Vybrané statě z akustiky* [online]. Ústav fyziky, Fakulta stavební, VUT Brno, [cit. 2013-08-20]. <http://fyzika.fce.vutbr.cz/doc/vyuka_schauer/vybrane_state_z_akustiky.pdf>.
- Properties of sound at czech wikiskripta (https://www.wikiskripta.eu/w/Vlastnosti_zvuku)

Bibliography

- MORNSTEIN, Vojtěch. *Lékařská biofyzika a přístrojová technika*. 1. edition. Neptun, 2001. pp. 396. ISBN 80-902896-1-4.
- NAVRÁTIL, Leoš – ROSINA, Jozef. *Lékařská biofyzika*. 1. edition. Manus, 2001 (1. dotisk). pp. 357. ISBN 80-902318-5-3.