Technical Acoustics and Noise Control *(lecture notes for self-learning)*

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Lecture 1.

Content:

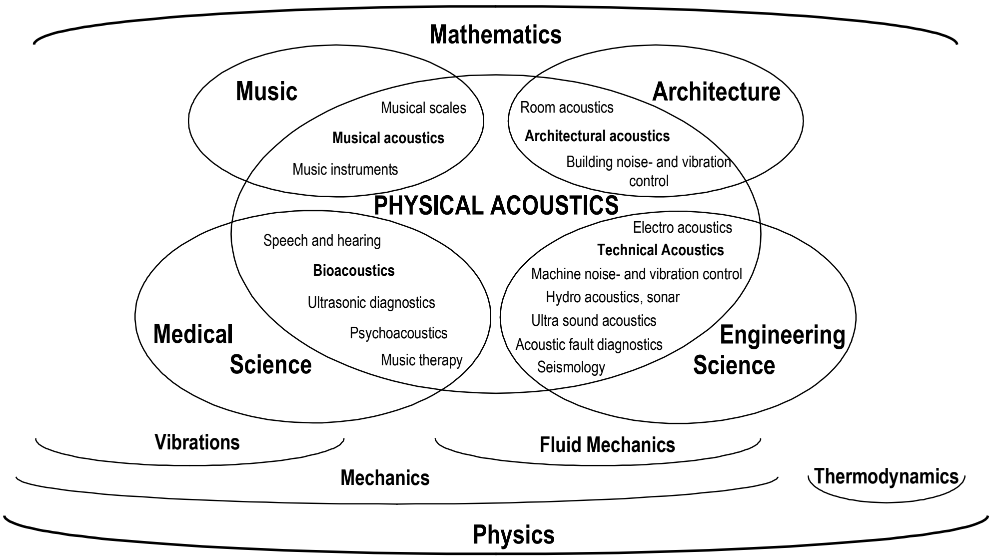
1.1. Introduction to acoustics

The subject of acoustics:

Acoustics is a science dealing with the origin, propagation, and death of sound and its effects on living organism specifically on the human body. In a narrower sense, acoustics deals only with the analysis of sounds perceived by human hearing, but this definition has long been obsolete for technical acoustics. According to a rigorous division of disciplines, within physics, acoustics is a chapter of classical mechanics. Due to its close connection with other fields of art and science, acoustics can be considered a separate discipline in physics.

Classification of acoustics and connection with other fields of science and art:

The interdisciplinary nature of acoustics is evidenced by its close relation with the fields of music, architecture, medicine and engineering. Within physics, it is primarily concerned with mechanics, fluid dynamics, and thermodynamics. The following figure shows the most important specializations and relationships of acoustics with other fields of art and science.



The division of acoustics, and connection with other fields of science and art

Like mechanics, acoustics makes extensive use of the tools of mathematics to enable the determination of numerical value of physical variables on process and engineering design, as well as a deeper understanding of scientific phenomena.

The concept of sound: In the physical sense, sound is a mechanical wave, the propagation of a state of mechanical disturbance in a continuous, flexible medium. Mechanical disturbance is a change in the equilibrium value of the mechanical variable of the medium (pressure, velocity,…). It is important to note that a single excitation results a single sound effect, while continuous excitation results continuous sound effect. According to the diversity of acoustics, sound can be defined differently, for example, in a subjective acoustic approach, sound is the phenomenon that causes a sense of sound.

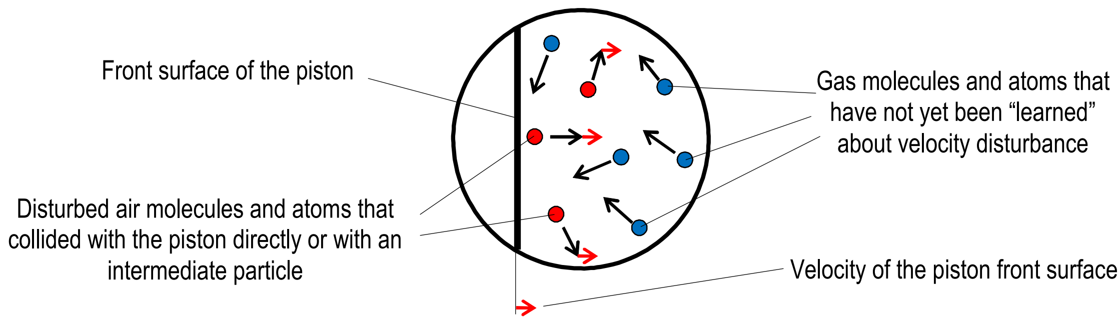
There are a number of significant differences between free-surface water waves and the sound propagating in the air, but the graphically expressive water surface wave is still clearly aided in understanding wave propagation. If a stone is thrown onto a dormant free surface of water before the stone sinks into the water, the stone will scatter the water in front of it, and then, after moving further down, the water will close above it. In this case, the mechanical disturbance is the deflection of the water parts from their rest position. During the phenomenon, the water move away and return will not rest in one place, but spreads in the form of concentric ring-shaped, free surface water waves, see next figure.

Free surface waves formed on the water surface

It is an important observation, that the motion of the fluid, can be observed during the wave propagation. The fluid particles deviate slightly around their equilibrium position in both the vertical and horizontal directions. But they do not pass at great distances from their original place, so there is no fluid flow or convection in the traditional sense. This is evidenced by the fact that after the attenuation of the wave, the shape and position of the free water surface remain the same as in the original, undisturbed state. The wave is the propagation of the deflection state of the particles (and not the particles).

The understanding of sound waves in a gaseous medium is further aided by a molecular explanation of sound propagation. To do this, imagine a long tube, the interior of which is filled with technical normal state air (t_0 = 20 ºC and $p_0 = 10^5$ Pa). One end of the tube is blocked by a piston, that can easily move and airtight. Consider air to be an ideal gas, in which case the extent of the particles (atoms and molecules) is point-like, and they interact each other only with elastic collision. Thus, an elastic collision, the front surface of the piston and the adjacent mixture of air forming gas molecules and atoms are in continuous dynamic contact.

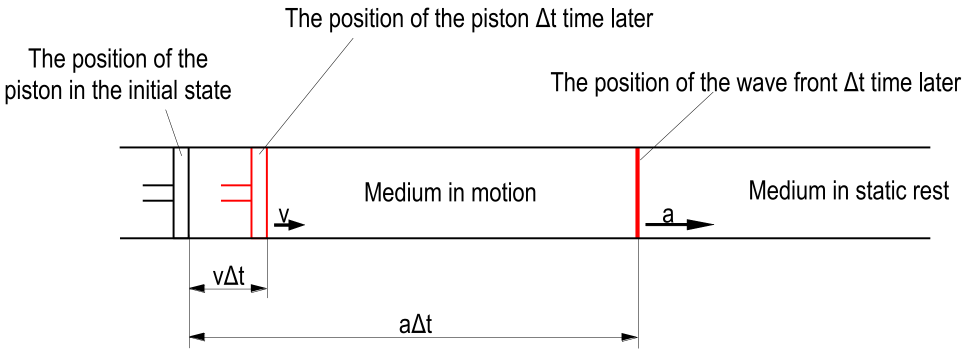
If the piston starts to move from left to right at a given moment with a velocity v, this velocity state is also transmitted to the air molecules and atoms in direct contact with the piston during elastic collisions. After making a mean free path length, the disturbed particles collide with new ones and thus the velocity state in the air moves one layer inward. As the collisions continue the disturbance state moves further in the tube.



The „molecular" explanation of sound propagation in an ideal gas

Shortly after the movement of the piston, the greatly magnified picture of the disturbance state is shown on the figure, with the disturbed red and undisturbed blue particles. The disturbance state is transmitted by the gas particles, so it can be seen that the disturbance propagation velocity and the average velocity of the mixture of gas atoms and molecules are in the same magnitude (t = 20 ºC, rounded to the sound velocity a= 343 m/s, and the average velocity of atoms and molecules v_p = 502 m/s).

The following figure shows a longer section of a tube filled with air, similar to the previous example. After the initial rest, the piston suddenly starts at speed v to the right. In connection with the movement in the tube, two important places can be marked after the time Δt. Due to its translational motion, the new position of the piston will be at a distance vΔt to the right of the initial state. The other important place is the position of the wave front, which separates the air parts that are already moving (where the disturbance has reached) and still resting (where the disturbance has not reached). Through the molecular heat motion detailed above, the wave front travels to the distance aΔt with the wave propagation velocity. After the time Δt relative to the initial state, the position of the piston and the wave front is shown in the following figure.



Δt time later to the initial state, the position of the piston and the wave front

Although vibration and wave are closely related (they are many sound created by the emission of vibrating surfaces), they are two separate physical concepts. Vibration means periodic behaviour around the equilibrium value, wave is propagation of the disturbance state. Both phenomena can also be found in other areas of physics (e.g., electric oscillation circuit, light wave, …).

The physical dual nature of sound: Consider sound as a completely new, unknown phenomenon. In order to expand our knowledge, we perform experiments with various physical measuring instruments (brightness meter, magnetic induction meter, Geiger-Müller counter, …). It has been observed, that instruments suitable for measuring flow rates (pressure, velocity) in gaseous media, indicate deviation in the presence of sound. Another group of observations suggests a wave phenomenon. Based on this, it can be concluded that sound has a dual, flow and wave nature. Recognition of flow and wave nature is important because, based on this, the mathematical and experimental methods used in flow and wave science can be used in acoustics, taking into account appropriate application conditions. Thus, for example, in the mathematical description of sounds formed in air, we will start from the basic equations of fluid mechanics.

Characteristics of the fluid flow nature of sound:

- Time variable (non-steady, the variable describing the sound space (□) is a function of time, $\partial \square / \partial t \neq 0$)

- Compressible (during the special, elementary fluid flow in sound propagation, the density of the medium is not constant $\rho \neq$ const. In an incompressible medium the mechanical disturbances occur at arbitrary distance in the same time as the excitation, and no sound field is formed.

- Small amplitude, (the change of a given acoustic variable due to sound (Δξ) is small, or the initial, equilibrium value (ξ_0) of the same acoustic variable is large, the ratio of the two values is small $\Delta\xi/(\xi\_0 \ll 1)$)

Phenomena indicating the wave nature of sound:

- Disturbance state propagation (Through sound, a mechanical state is transferred from one point in space to another without macroscopic fluid flow)

- Interference (A new wave modification, characterized by spatially stabilized locations of constructive and destructive sections, at the composition of two or more waves of the identical frequency. A typical example in acoustics such as standing wave.)

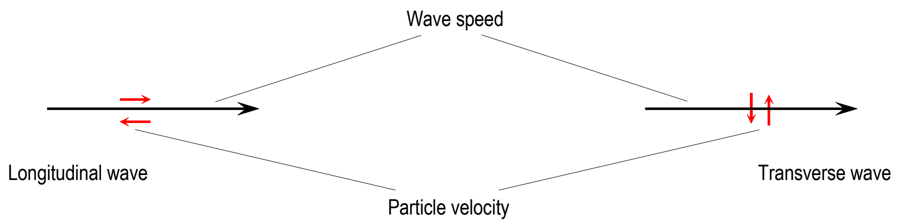
- Diffraction (According to acoustic interpretation, the diffraction of sound is the propagation of sound into its own geometric shadow zone. For example, in open space, away from sound-reflecting surfaces, the speech of the person with the back to us becomes audible due to sound diffraction.)

- Refraction (In acoustics the refraction is the abrupt change in the direction of sound propagation in the new medium, incident obliquely to the boundary of different media. At refraction, the component of the sound speed perpendicular to the surface changes and its parallel component remains unchanged.)

- Reflection (Acoustic reflection, is the abrupt change in the direction of sound propagation incident to the boundary of different media in the original medium, during the component of the speed of sound perpendicular to the reflecting surface changes sign and its parallel component remains unchanged.)

Note: The phenomena of diffraction, refraction, and reflection, and all of the general changes in sound propagation compared to previous conditions, is called sound scattering.

Longitudinal and transverse waves: Mechanical waves are classified into longitudinal and transverse categories based on the relationship between the elementary flow velocity (particle velocity) and the wave propagation velocity (sound velocity) directions. In the case of a longitudinal wave, the direction of particle motion and wave propagation are parallel to each other, and in the case of a transverse wave, the direction of particle motion and wave propagation are perpendicular to each other. In addition to the two basic types, other waves (Rayleigh, Lamb, torsion wave, …) are known in acoustics, but all of them can be derived from the previous two basic types.

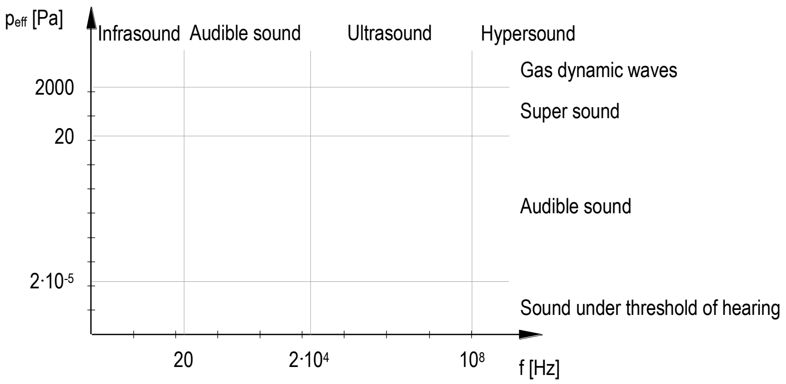


Longitudinal and transverse waves based on the direction of particle velocity and wave propagation

Both gaseous, liquid and solid elastic media have a high resistance to volumetric deformation during the propagation of longitudinal waves, so that a longitudinal wave can form in all three media. In contrast to shear motion during transverse wave propagation, only in the solid elastic medium will form force, so that a transverse wave can be detected primarily in a solid elastic medium. (An interesting exception to this is the free surface water wave, in which the velocity of the liquid particles has both a parallel and perpendicular component to the direction of wave propagation and the particles move in an elliptical path. The propagation of the state of motion in the vertical direction is not caused by the shear force of the water layers, but created by the effect of gravity.)

Sound as a function of the transmitting medium: Depending on whether the mechanical wave is formed in an gaseous, liquid, or solid elastic medium, it is called air borne sound, liquid borne sound, or structure borne sound, respectively. In mechanical engineering noise control, the effects of noise on the auditory organ are mostly transmitted through the air, so in this note we deal primarily with airborne sounds.

Airborne sounds as a function of frequency and effective sound pressure: Sounds propagating in air or other gases can be divided into 4-4 ranges along the frequency and effective sound pressure. Each of these belong to a separate acoustics area. The values separating the ranges are partly determined by human sound perception (in the frequency range of approximately 20Hz – 20kHz and between 20μPa – 20Pa effective sound pressure) and partly by the application limits of the mathematic models. The name of the acoustic area and the limit values are summarized in the following figure.



Naming of sounds as a function of frequency and effective sound pressure

1.2. Test questions and solved problems

T.Q.1. Define the concept of sound and describe the properties of its dual nature!

T.Q.2. Specify the lower and upper limits of the frequency and effective sound pressure ranges for sounds sensible to the human ear!
