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Acoustic Impedance

Acoustic impedance is the opposition of a medium to a longitudinal wave motion. It characterizes the relationship between the acting sound pressure and the resulting particle velocity. This impedance is called the specific acoustic impedance of the medium because it characterizes the medium itself. When a sound source transfers its energy to a medium, however, the medium opposes the movement of the source with some kind of average impedance that is dependent not only on the medium, but also on the size of the air mass pushed by the sound source. Similarly, in some cases the medium itself can vibrate as a mechanical system (e.g., air columns in pipes and horns) and it is characterized by standing waves rather than propagating waves. Therefore, in acoustics another type of impedance is needed that is analogous to the mechanical flow impedance in a hydraulic system (which determines the ratio of the fluid pressure to the amount of fluid flowing through a pipe in a unit of time). This analog to mechanical flow impedance is called acoustic impedance (or acoustic flow impedance).

Specific acoustic impedance and acoustic impedance characterize different physical situations; however, in many specialized articles and books only one of these terms is needed. For example, the concept of specific acoustic impedance is used in room acoustics and outdoor sound propagation, and the concept of acoustic impedance applies to situations considered in music acoustics and electroacoustics. In such cases, the same term—acoustic impedance—can be used and it is important to realize which of the two impedances is considered.

Specific acoustic impedance (*z*) (characteristic impedance, wave impedance) is the opposition of a medium to wave propagation, and it depends on the medium properties and the type of wave propagating through the medium. The specific impedance of a medium opposing the propagation of a plane sound wave is equal to:

$$z = \sqrt{K \times \rho} \qquad (1)$$

where K is the stiffness of the medium in N/m^2 and ρ is the density of the medium in kg/m^3. If we isolate K from Equation 5.1 in the text (i.e., $K = c^2\rho$) and enter it into the above equation (and simplify the equation), we can relate acoustic impedance to the speed of sound in a medium.

$$z = \rho \times c \qquad (2)$$

where ρ is the medium density in kg/m^3 and c is the speed of sound in m/s. Thus, the acoustic impedance that is acting in opposition to the wave propagation increases with an increase in medium density as well as an increase in the speed of sound.

The specific acoustic impedance of air changes with temperature since both the medium density and the speed of sound depend on temperature. The unit of specific acoustic impedance is the rayl (Ry), which is equal to 1 $kg/(m^2s)$ or 1 Ns/m^3. For air, z = 428 Ry at 0°C and z = 413 Ry at 20°C. For water, z = 14.8 MRy.*

The specific acoustic impedance determines the propagation conditions for sound waves moving through a medium or transmission conditions for sound energy moving from one medium to another, such as from air to the wall of a room (see Chapter 6). So a large sound pressure will create a large particle velocity if the impedance of the medium is low, but the same sound pressure will create only a relatively small particle velocity if the acoustic impedance of the medium is high.

As discussed above, the *specific* acoustic impedance needs to be differentiated from the acoustic impedance of a vibrating mass of air, which is seen in enclosed air masses, such as air in a tube or in an organ pipe. In these cases, the acoustic impedance depends not only on the type of medium, but also on the dimensions of the enclosed volume. The **acoustic impedance** (*Z*) specifies the impedance offered by an enclosed volume of air and it determines the value of the **volume velocity** (*U*, also called the medium flux). The volume velocity is the volume of fluid or gas that passes a given surface area per unit of time after an acoustic pressure is applied. In other words, the volume velocity indicates how many particles (from a volume point of view) move past a certain plane. A large pressure means more particles are moving farther; therefore, it results in a greater volume velocity.

Specific acoustic impedance (*z*) is "point impedance," that is, the impedance that indicates the pressure–velocity relationship at one specific point in unbound space. In contrast, acoustic impedance (*Z*) is the ratio of the averaged sound pressure across a hypothetical finite surface. For example, acoustic impedance is used to calculate how much power a given acoustic system is producing across its radiating surface.

To better understand the concept of acoustic impedance, let us corroborate the concept of a hydraulic system mentioned in Chapter 5 a little bit further. Consider a hydraulic system in which a fluid flows under a certain external (hydraulic) pressure (*p*). The amount of fluid (*Q*) that can pass through a pipe in a unit of time is determined by the velocity of the fluid (*v*) and the cross-sectional area of the pipe (*A*). Thus:

$$Q = v \times A \tag{3}$$

The opposition to the flow of fluid in a hydraulic system is mechanic flow impedance:

$$Z_h = \frac{p}{Q} = \frac{p}{v \times A} = \frac{Z}{A} \tag{4}$$

where Z_h is opposition offered by the hydraulic system to the flow of fluid, *p* is the external pressure causing the fluid to flow, *v* is the velocity of the fluid, *Z* is the mechanical impedance of the fluid, and A is the cross section of the opening through which the fluid flows. As you can see in Equation 4, the mechanic flow impedance is the mechanic impedance per unit of surface that the energy is passing. The same relationship exists between acoustic impedance (Z) and specific acoustic impedance (z); that is:

$$Z = \frac{z}{A} \tag{5}$$

The larger the surface of a radiating sound source or the cross section of a column of air is, the lower the acoustic impedance that opposes its motion. The unit of acoustic impedance is the acoustic ohm (Ns/m^5).

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* Temperature has a negligible effect on the acoustic impedance of fluids, so only one value is provided for water.