# Acoustic Impedance

Related terms:

Ultrasonics, Impedance, Plane Waves, Sound Waves, Attenuation, Transducers-, Shock Waves, Amplitudes, Ultrasound

View all Topics

## Physical Medicine and Rehabilitation

R. Alkins, K. Hynynen, in Comprehensive Biomedical Physics, 2014

### 10.08.3.1 Reflections

The acoustic impedance, $z$, of a material is the ratio of acoustic pressure to the associated particle speed (Kinsler et al., 2000). It can be shown that for plane waves this is equal to the product of the density and the speed of sound in the medium. The acoustic impedance at 20 °C for air, distilled water, and bone is 415, $1.48 \times 10^6$, and $5.3 \times 10^6$ Pa s $m^{-1}$, respectively (Hatakeyama et al., 2000). Given that the bulk of soft tissue comprises water, it stands to reason that the acoustic impedances of soft tissues in the body are not significantly different from that of water. Adipose tissue does have a slightly lower acoustic impedance due to its lower density and speed of sound. The major exceptions are the lungs, which have a much lower acoustic impedance due to the vast number of air spaces ($0.1 \times 10^6$ Pa s $m^{-1}$ inflated, $1.4 \times 10^6$ deflated Pa s $m^{-1}$; Oelze et al., 2008), and bone, which has a higher density and speed of sound and thus a higher impedance ($4–8 \times 10^6$ Pa s $m^{-1}$; Laugier and Haïat, 2011).

For a normally incident ultrasound wave to an interface between materials of acoustic impedance $z_1$ and $z_2$, it can be shown that the intensity reflection and transmission coefficients, $R$ and $T$, are

(3)

(4)

where $R + T = 1$. It can then be seen that if $z_1 = z_2$, $R = 0$ and all of the wave's energy is transmitted; this is essentially the case in soft tissues, where the acoustic impedances are similar and losses from reflections are small. At tissue–air interfaces, however, virtually the entire incident wave is reflected back into the tissue. At soft tissue–bone interfaces, about 60–70% of normally incident waves are transmitted. For obliquely incident waves at a soft tissue–bone interface, the transmitted wave decreases up to the critical angle of 25–30°, at which point all of the wave is reflected.

The above is true for longitudinal waves beyond Snell's critical angle, but in fact at tissue–bone interfaces, there is mode conversion of the incident longitudinal wave to a shear wave. The speed of a longitudinal wave in tissue is similar to that of a shear wave in bone, and as a result there is better acoustic impedance matching between these modes (Clement et al., 2004). This is of practical significance primarily for transcranial imaging; although there tends to be less distortion with shear wave propagation through the skull, there is more attenuation and heating of the skull (White et al., 2006), which could lead to complications in high- power therapeutic applications.

> Read full chapter

# Characterization of Liquids, Nano- and Microparticulates, and Porous Bodies Using Ultrasound

Andrei S. Dukhin, Philip J. Goetz, in Studies in Interface Science, 2010

## 3.3 Propagation Through Phase Boundaries: Reflection

Acoustic impedance is a very convenient property for characterizing effects that occur when the sound wave meets the boundary between two phases. There are certain similarities between longitudinal ultrasound and light reflection and transmission through the phase boundaries. For instance, the ultrasound reflection angle from a plane surface is equal to the incident angle which is the same as for light (see Figure 3.2):

Figure 3.2. Illustration of the sound propagation through a phase boundary.

(3.15)

where the index *i* corresponds to the incident wave and index *r* corresponds to the reflected wave.

The transmitted wave angle must satisfy wavefront coherence at the border. Again, this yields the same relationship as with light transmission:

(3.16)

where indexes 1 and 2 correspond to the different phases.

Propagation of the sound wave through the phase border should not create any discontinuities in pressure or the particle's velocity. This condition yields the following relationships for the pressure in the reflected and transmitted waves:

(3.17)

(3.18)

In the case of normal incidence, when $\theta_i = \theta_t = 0$, these equations simplify to:

(3.19)

and

(3.20)

From these equations, an important relationship is derived between the phases of the reflected and incident waves. If $Z_2 > Z_1$, then the reflected pressure wave is in phase with the incident wave; otherwise, it is 180° out of phase.

The pressure value determines the intensity of the ultrasound, *I*:

(3.21)

For normal incidence, we can use Equations (3.19) and (3.20) to obtain the ultrasound intensity of the reflected and transmitted waves:

(3.22)

and

(3.23)

At normal incidence, the reflected wave interferes with the incident wave. This leads to the buildup of standing waves. For a perfect reflector, the particle displacement in reflected and incident waves compensate each other completely when they are out of phase. They add together when they are in phase. This leads to a repeating pattern of nodes and maxima. Standing waves do not transmit any power, since the power coming back equals the power going out.

Standing waves can superimpose with the traveling waves when the reflection is not perfect. This effect occurs when ultrasound propagates through a multilayer medium. The case of three phases is important and well characterized. A standing wave appears in the first and the second layers. They superimpose here with traveling waves if reflection at the phase boundaries is not perfect.

In the case of normal incidence, it is possible to derive [5] an analytical expression for the intensities of the incident and transmitted waves:

(3.24)

where $l_2$ is the thickness of the second layer.

One important conclusion follows from Equation (3.24). There are two cases when the second layer becomes transparent for ultrasound propagation. The first one is rather obvious; it happens when the thickness of the second layer is much less than the wavelength . The second case is related to the standing waves built up in the intermediate layer, when $l_2 = n\lambda_2/2$. These conditions are important for designing acoustic and electroacoustic devices.

> Read full chapter

# Acoustic components

Leo L. Beranek, Tim J. Mellow, in Acoustics: Sound Fields and Transducers, 2012

### 4.6 Intermediate-sized tube—mixed mass-resistance element [$a$ (in meters) > 0.01/  and $a$ < 10/$f$] [2]

The acoustic impedance for a tube with a radius $a$ (in meters) that is less than 0.002/ was given by Eqs. (4.14) and (4.16). Here we shall give the acoustic impedance for a tube whose radius (in meters) is greater than 0.01/  but still less than 10/$f$. For a tube whose radius lies between 0.002/  and 0.01/  interpolation must be used. The acoustic impedance of the intermediate-sized tube is equal to

(4.22)

where

(4.23)

(4.24)

$a$ is radius of tube in m.
$\rho_0$ is density of air in kg/m$^3$.
$\mu$ is viscosity coefficient. For air $\mu = 1.86 \times 10^{-5}$ N · s/m$^2$ at 20°C and 0.76 m Hg. This quantity varies with temperature, that is, $\mu \propto T^{0.7}$, where $T$ is in °K.
$l'$ is actual length of the tube.
$l''$ is end correction for the tube. It is given by Eq. (4.5) if the tube is flanged or Eq. (4.8) if the tube is unflanged. The numbers (2) in parentheses in Eqs. (4.23) and (4.24) must be used if both ends of the tube are being considered. If only one end is being considered, replace the number (2) with the number 1.
$\omega$ is angular frequency in rad/s.

> Read full chapter

# Sound in Waveguides

Frank Fahy, in Foundations of Engineering Acoustics, 2001

### 8.6.2 Transmission of Plane Waves Through an Abrupt Change of Cross-sectional Area and an Expansion Chamber

The acoustic impedance of a uniform tube that carries only progressive plane waves is given by Eq. (4.17) as ± $\rho_0 c/S$, where $S$ is the cross-sectional area of the tube. If this area changes abruptly at some point, the associated change of impedance will cause incident waves to be reflected. The acoustic flow field in immediate vicinity of the area discontinuity cannot be one-dimensional and plane. Non-plane sound fields are generated but, at low frequencies, they are confined to the immediate vicinity of the discontinuity, and only plane waves can propagate and transport energy. The effect of the discontinuity is to introduce an additional inertial impedance associated with the local kinetic energy of the non-planar particle motion. It may be represented by a lumped acoustic element, as explained in Chapter 4.

In the case of a junction between two circular section tubes of considerably different diameter, as illustrated in Fig. 8.10, the inertial acoustic impedance of the junction is nearly always much less than the plane wave impedance of the narrower of the tubes, and can then be safely neglected. Consequently, plane wave pressures on either side of the junction may be assumed to be equal. As shown in Chapter 4, the elastic impedance of this local fluid region is relatively so high that it can be assumed that the volume velocities on either side of the junction are also equal.

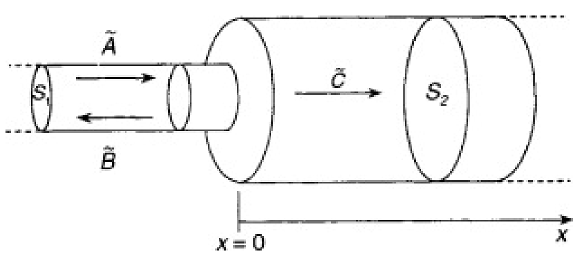


Fig. 8.10. Abrupt change in cross-sectional area.

For the purpose of studying the acoustic effect of a junction in isolation, it is assumed that it joins two anechoically terminated tubes. The harmonic wave system shown in Fig. 8.10 is represented by incident, reflected and transmitted waves of complex amplitudes . The junction is at $x = 0$. Pressure equality gives

(8.40)

Volume velocity equality gives

(8.41)

The reason why wave reflection must occur is now obvious: both equations cannot be satisfied if $S_1 \neq S_2$ and is zero. The solution for the ratio of transmitted to incident wave pressure amplitudes is

(8.42)

where $m = S_1/S_2$. Note that the pressure amplitude ratio is different for sound incident from the two directions; it is greater than unity for sound incident upon a contraction ($m > 1$) and less than unity for sound incident upon an expansion. Consequently, care must be exercised in quantifying the effect of the impedance discontinuity in terms of sound pressure levels. The reflected wave interferes with the incident wave to produce a spatial variation of pressure amplitude on the incident side of the area discontinuity. As explained above, it is safer, and less ambiguous, to define the performance in terms of the ratio of transmitted to incident sound *powers.*

The ratio of power carried by the transmitted wave to that carried by the incident wave, which is the sound power transmission coefficient of the junction, is given by the product of the cross-sectional areas and the plane wave intensities as

(8.43)

Unlike the pressure ratio, it is less than unity in both cases and decreases with increase in *m*. It is the same in both directions, or reciprocal. Since the area discontinuity is assumed to dissipate no energy, the *net* powers are equal on both sides.

The reflecting effect of a change of section is exploited in the design of internal combustion exhaust system mufflers, of which a major component is the expansion chamber, illustrated in Fig. 8.11. The acoustic impedance at the left-hand inlet (F) to the expansion chamber equals that of the larger diameter tube of length $L$ terminated at G by that of the smaller diameter tube ($\square_0 c/S_1$). The specific acoustic impedance transfer expression (8.24) may be adapted for acoustic impedance by replacing $z\square_t$ by the acoustic impedance ratio $z\square_t = Z_t S_0/\square_0 c$, where $S_0$ is the cross-sectional area of the tube to which the transfer expression applies. Hence, $Z\square_G = (\square_0 c/S_1)(S_2/\square_0 c)$ and

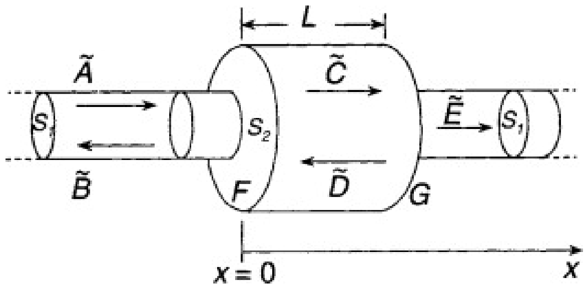


Fig. 8.11. Expansion chamber.

(8.44)

The acoustic impedance ratio presented to the incident wave in the smaller-diametertube is $Z_F S_1/\square_0 c = mZ\square_F$. Now, $/\tilde{A} = (mZ\square_F - 1)/(mZ\square_F + 1)$, giving the ratio of transmitted to incident sound powers as

(8.45a)

Values derived from Eq. 8.45a for an area ratio of ten are plotted in Fig. 8.12 in terms of the sound power transmission loss. Frequencies for which $\sin kL = 0$ are the natural frequencies of the closed expansion chamber at which the impedance at F equals that at G, so that the expansion chamber is ‘short circuited’ and the transmission loss is zero. At intermediate frequencies corresponding to cos $kL = 0$, the impedance ratio at F equals the *inverse* of that at G and  takes a minimum value given by

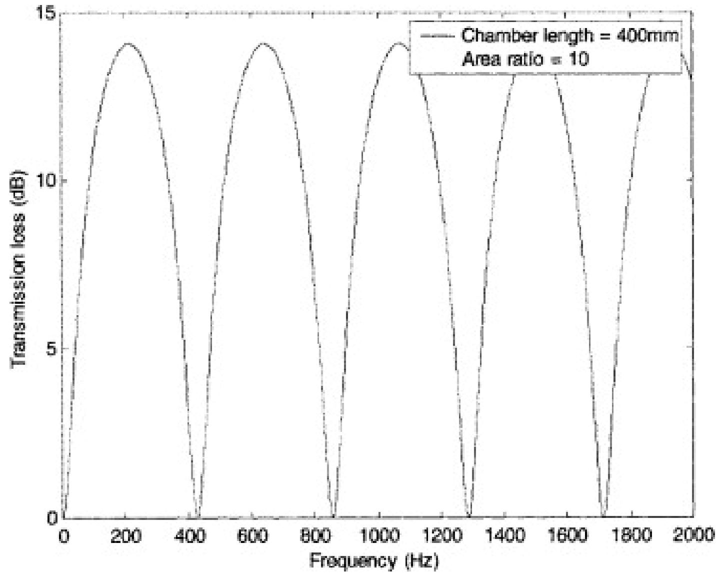


Fig. 8.12. Transmission loss produced by an expansion chamber with an area ratio of ten.

(8.45b)

The expressions derived above apply to an abrupt change of section that joins ducts of any uniform cross-section. In cases where the transition is less abrupt, such as a short conical adaptor for example, these expressions only apply approximately if the transition length is much less than a wavelength; otherwise, an acoustic horn model is required (see Section 8.11).

> Read full chapter

# Polymers, Ferroelectric

T.C. Mike Chung, A. Petchsuk, in Encyclopedia of Physical Science and Technology (Third Edition), 2003

## I.E Acoustic Impedance Z

The acoustic impedance *Z* is a parameter used for evaluating the acoustic energy transfer between two materials. It is defined as $Z_2$ = pressure/volume · velocity. In solid material,

(11)

where $\rho$ is the density and $c$ is the elastic stiffness of the material.

Piezoelectric ferroelectrics fall into four classes: optical active polymers, poled polar polymers, ferroelectric polymers, and ceramic/polymer composites. *The poling procedure involves the application of an external field to a ferroelectric to induce a cooperative alignment of constituent dipoles.* Most polymers in the first group are biological materials, such as derivatives of cellulose, proteins, and synthetic polypeptides. The origin of piezoelectricity in these polymers is attributed to the internal rotation of the dipoles of asymmetric carbon atoms, which gives rise to optical activity. The second class of piezoelectric polymers includes polyvinyl chloride (PVC), polyvinyl fluoride (PVF), polyacrylonitriles (PAN), odd-numbered nylons, and copolymers of vinylidene cyanide. The piezoelectricity in these polymers is caused by the trifluoroethylene (TrFE) or tetrafluoroethylene (TFE). Recently, other polymers were found to show ferroelectric behavior, such as copolymers of vinylidene cyanide, odd-numbered nylons, and polyureas, in which piezoelectricity arises from the functional polar groups in the polymer molecules. In the fourth class (polymer/ceramic composites), the piezoelectric activity comes from the intrinsic piezoelectricity of ceramics. Physical properties of these composites can be controlled by the choice of the ferroelectric ceramics and the polymer matrix. They have a combination of high piezoelectric activity from the ferroelectric ceramics and flexibility from the polymer matrix.

Table I compares the piezoelectric properties of the ferroelectric ceramics and polymers. The piezoelectric strain constant $d_{31}$ of polymers is relatively low compared to that of ceramics. However, the piezoelectric voltage constant $g_{31}$ is larger. In addition, polymers have a high electromechanical coupling factor and low acoustic impedance, which permit their use in ultrasonic transducer applications and medical instrumentation. The combination of these properties with their flexibility, light weight, toughness, and availability in large-area sheets has led to tremendous growth in research on novel ferroelectric polymers.

TABLE I. Typical Physical, Piezoelectric, and Pyroelectric Properties of Various Materials

| **Material**[a] | **Density $\rho$ (g/cm3)** | **Modulus $C_{11}$ (GN/m2)** | **Piezoelectric constants** | | | **Pyroelectric constant (μC/K-m2)** | **Dielectric constant ($\varepsilon_r$)** | **Coupling factor $k_{31}$** | **Acoustic impedance (Gg/m2-sec)** |
|---|---|---|---|---|---|---|---|---|---|
| | | | **$d_{31}$(pC/N)** | **$e_{31}$(pC/N)** | **$g_{31}$(mV-m/N)** | | | | |
| PVDF | 1.78 | 1–3 | 20 | 6.0 | 174 | 30–40 | 10–15 | 0.1 | 2–3 |
| P(VDF/TrFE) | 1.9 | 1.2 | 15–30 | 2–3 | 100–160 | 30–40 | 15–30 | 0.2 | |
| PVF | 1.4 | 1 | 1 | | | 10 | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PVC | 1.5 | 4 | 1 | | | 1–3 | 3 | |
| Nylon-11 | 1.1 | 1.5 | 3 | 6.2 | | 3 | 4 | 0.1–0.15 |
| Nylon-11/PVDF | | 2.3 | 41 | 109 | | | 13.8 | |
| Laminate film | | | | | | | | |
| P(VDCN/VAc) | 1.2 | 4.5 | 6 | 2.7 | 169 | | 4.5 | 0.06 |
| PTUFB | | | | | | 3.0 | 20–30 | |
| PVDF/PZT | 5.3 | 3.0 | 20 | 6.0 | 19 | | 120 | 0.07 |
| Rubber/PZT | 5.6 | 0.04 | 35 | 1.4 | 72 | | 55 | 0.01 |
| POM/PZT | 4.5 | 2.0 | 17 | 3.4 | 20 | | 95 | 0.08 |
| Quartz | 2.65 | 77.2 | 2 | 15.4 | 50 | | 4.5 | 0.09 |
| PZT | 7.5 | 83.3 | 110 | 920 | 10 | | 1200 | 0.31 |

a PVDF, poly(vinylidene fluoride); P(VDF/TrFE), poly(vinylidene fluoride-co-trifluoroethylene); PVF, polyvinyl fluoride; PVC, polyvinyl chloride; P(VDCN/Vac), poly(vinylidene cyanide-co-vinyl acetate); PTUFB, polyurea–formaldehyde; PZT, lead zirconate titanate.

> Read full chapter

# Introduction and terminology

Leo L. Beranek, Tim J. Mellow, in Acoustics: Sound Fields and Transducers, 2012

## Acoustic impedance ($Z_A$). (American standard acoustic impedance)

The acoustic impedance at a given surface is defined as the complex ratio [6] of effective sound pressure averaged over the surface to effective volume velocity through it. The surface may be either a hypothetical surface in an acoustic medium or the moving surface of a mechanical device. The unit is $N \cdot s/m^5$, or $rayls/m^2$. [7]

(1.9)

## Specific acoustic impedance ($Z_s$)

The specific acoustic impedance is the complex ratio of the effective sound pressure at a point of an acoustic medium or mechanical device to the effective particle velocity at that point. The unit is $N \cdot s/m^3$, or rayls. [8] That is,

(1.10)

## Mechanical impedance ($Z_M$)

The mechanical impedance is the complex ratio of the effective force acting on a specified area of an acoustic medium or mechanical device to the resulting effective linear velocity through or of that area, respectively. The unit is N·s/m, or rayls·$m^2$. That is,

(1.11)

## Characteristic impedance (□$_0$c)

The characteristic impedance is the ratio of the effective sound pressure at a given point to the effective particle velocity at that point in a free, plane, progressive sound wave. It is equal to the product of the density of the medium times the speed of sound in the medium (□$_0c$). It is analogous to the characteristic impedance of an infinitely long, dissipationless electric transmission line. The unit is N·s/$m^3$ or rayls.

In the solution of problems in this book we shall assume for air that

which is valid for a temperature of 22°C (71.6°F) and a static pressure of $10^5$ Pa.

> Read full chapter

# Horn loudspeakers

Leo L. Beranek, Tim J. Mellow, in Acoustics: Sound Fields and Transducers, 2012

## Cutoff frequency

The special case of $m = 4\pi/$□ occurs at a frequency which we shall designate $f_c$, where

(9.49)

This frequency $f_c$ is called the cutoff frequency because, for frequencies lower than this, no power will be transmitted down the horn, i.e., the impedance at all positions along the horn is purely reactive [see Eq. (9.46)]. The throat impedance of an infinite exponential horn is plotted in Fig. 9.9.

To obtain the acoustic impedance at the throat of the horn in terms of the cutoff f requency, we observe that $f_c/f = m/2k$. Substituting in Eq. (9.45) yields

(9.50)

where

$S_T$ is throat area in $m^2$.
$\rho_0 c$ is characteristic impedance of air in rayls.
$f_c$ is cutoff frequency.
$f$ is driving frequency.

Graphs of two quantities *A* and *B* that are directly proportional to the resistive and reactive parts of the acoustic impedance at the throat of an infinitely long exponential horn are shown in Fig. 9.8. The quantities *A* and *B* also are directly proportionaf to the real and imaginary parts of the acoustic admittance at the throat. The relations among *A*, *B*, $R_{AT}$, $X_{AT}$, $G_{AT}$, and $B_{AT}$ are given on the graph. When the frequency is greater than approximately double the cutoff frequency $f_c$, the throat impedance is substantially resistive and very near its maximum value in magnitude.

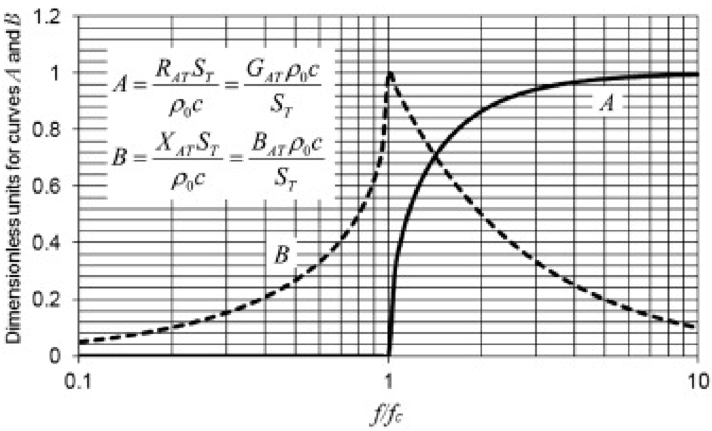


Fig. 9.8. Plot of the quantities *A* and *B*, which are defined by the relations given on the graph.

> Read full chapter

# VIBRATION GENERATED SOUND | Fundamentals

M.P. Norton, S.J. Drew, in Encyclopedia of Vibration, 2001

## Acoustic near field and impedance

The mechanical and acoustic impedances of any vibrating sound source are determined at the surface of the solid, which is the interface between the solid and the surrounding fluid. This interface is in the acoustic near field. The combined mechanical and acoustic radiation impedances give the total impedance. For the baffled circular piston of radius *a*, mass *m*, stiffness $k_p$, damping $c_v$ and wavenumber $k$ ($k = \omega/c$):

(5)

(6)

(7)

For the baffled piston, the impedances are known. Piston velocity is calculated from the known mechanical force applied to the piston and the known mechanical impedance. Piston velocity and radiation impedance are then used to determine the radiated sound field (e.g., sound power). For many engineering structural sound sources, it is not practical to determine the applied mechanical force or mechanical impedance. However, it is not necessary to know them, in order to determine useful information about the radiated sound field. A single lineal structural vibration velocity term is sufficient to describe the radiation of vibration generated sound from a vibrating solid body. It is the space (—) and time (□□) averaged RMS surface normal velocity , i.e., the component of surface vibration velocity that is normal to the surface at every point.

If the surface normal vibration velocity and the radiation impedance of the vibrating structure are both known, then the sound radiation can be determined from:

(8)

Radiation impedance for a baffled piston is shown in Figure 1. It is complex and varies with distance from the piston. The resistive (real) part of the radiation impedance is due to the radiated sound pressure. The reactive (imaginary) part of the radiation impedance is a fluid loading term, due to the fluid in close proximity to the piston. Fluid loading is significant when the fluid is a liquid. The primary effect of significant fluid loading is to reduce the vibration velocity of the piston and thus reduce the sound power radiated. Fluid loading is usually negligible for sound radiation in air, except for very thin structures.

Figure 1. Radiation impedence functions for a circular piston ($x = 2ka$). Used with permission from Norton MP(1999).

> Read full chapter

# Acoustical Measurement

Allan J. Zuckerwar, in Encyclopedia of Physical Science and Technology (Third Edition), 2003

## I.E.3 Direct Measurement of Sound Pressure and Volume Velocity

For measurement of the acoustic impedance within an acoustic device, the sound pressure can be measured with the aid of a probe tube (Section I.A.8), but measurement of the acoustic particle or volume velocity is difficult (Section I.C).

The most common method of attacking the latter problem is to control the volume velocity at the transmitter. This can be achieved in several ways: (1) by mounting a displacement sensor on the driver; (2) by using a dual driver, directing one side to the test region and the other side to a known impedance $Z_k$ and using $U = p/Z_k$ and (3) by exciting a driving piston with a cam so that the generated volume velocity will be independent of acoustic load. The first two methods rely on the integrity of the velocity measurement technique: the third is limited to relatively low frequencies. To measure the specific acoustic impedance of a material, a transmitter, receiver, and test specimen are mounted in a coupler; the impedance of the latter must be taken into account.

> Read full chapter

# Linear Acoustic Equations

Roger Ohayon, Christian Soize, in Structural Acoustics and Vibration, 1998

## Boundary conditions in terms of □

We express the boundary condition presented in Section 2.4in terms of field □(**x**, □).

1- Neumann boundary condition on □. Substituting Eq. (78-2)into Eq. (14)yields the Neumann condition on □,

(88)

**2- Neumann boundary condition on** □*z*with wall acoustic impedance. Substituting Eqs. (78-2)and (85)into Eq. (16)yields the Neumann condition on □*z*,

(89)

3- Dirichlet boundary condition on □0. From Eq. (26), since *p*(**x**, □) is equal to zero on □0, Eq. (85)yields *π*(□) = *i*□□*0*□(**x**, □) for all **x** in □0, which shows that □(**x**, □) is independent of **x** on □0. Consequently, since □(**x**, □) is defined to within an additive constant, this constant is removed by choosing

(90)

We then deduce that *π*(□) = 0 in Eq. (85)and consequently, *p* = -*i*□ □*0* □.

> Read full chapter