Architectural Acoustics

Week 3 Exercises : Fundamentals of Acoustics

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Figure 1. An 'omni-directional' sound source (www.bksv.com).

Especially for room acoustic purposes, a sound source as shown in Figure 1 is often used. The source is designed to produce a sound pressure that has the same amplitude in all directions, i.e. an omni-directional source. In this exercise, we assume a sound speed of *c = 340* m/s and a density of air $\rho_0 = 1.2$ kg/m^3.

We can express the pressure due to the source for frequency $f = \frac{\omega}{2\pi}$ as:

$$p(r,t) = \frac{A(\omega)}{r} e^{j(\omega t - kr)}, \tag{1}$$

with $A(\omega)$ related to the sound power of the source. Note that the pressure only depends on one spatial variable, *r*. To use this relation for computing intensity, power or sound pressure levels, we need to be in the far field from the source, that means *kr >> 1*, with *r* the distance to the source.

Question 1

At a distance of 10 m from the source, above what frequency is equation (1) valid?

Equation (1) can also be written as:

$$p(r,t) = \hat{p}(r,\omega) e^{j(\omega t - kr)} \tag{2}$$

with $\hat{p}(r,\omega)$ the amplitude of the pressure.

Question 2

Compute the level difference ΔL between the sound pressure level at *r* = 100 m and at *r* = 200 m due to the sound source.

When using this sound source to measure distant propagation outdoors, the effect of air attenuation should be included. To include the effect of air absorption in the pressure function, we write:

$$p_m(r,t) = \frac{A(\omega)}{r} e^{j(\omega t - \underline{k}r)} = \hat{p}(r,\omega,m) e^{j(\omega t - kr)}, \quad (3)$$

with

$$\underline{k} = k - j\frac{m}{2},$$

and with m the attenuation constant of air. For f = 1000 Hz, m = 0.001 m^{-1}.

Question 3

Compute the level difference ΔL between the sound pressure level at r = 100 m and at r = 200 m including air attenuation at 1000 Hz.

To compute the sound pressure level from the sound source, equation (1) can be used, but $\hat{p}$ is yet unknown. A way to compute the sound pressure level is to make use of the total sound power of the source. For an omni-directional sound source, the radiated sound power P_r can be related to the sound pressure amplitude as:

$$P_r = \int_S I_r dS = I_r(r) 4\pi r^2 = \frac{\tilde{p}^2}{Z_0} 4\pi r^2 = \frac{\hat{p}^2}{2Z_0} 4\pi r^2, \quad (4)$$

with I_r the sound intensity in radial direction, $\tilde{p}$ the root-mean-square value of the pressure, and $Z_0 = \rho_0 c$ the impedance of air. We assume that our sound source is a 'breathing sphere' with a radius of a = 0.2 m, and a velocity at the surface a of

$$v_r(r = a, t) = \hat{v}_a e^{j\omega t}, \quad (5)$$

with

$\hat{v}_a$ = 0.1 m/s.

Now, the sound power P_r is also related to the velocity of our source by:

$$P_r = \frac{1}{2} \hat{v}_a^2 Re(Z_r), \quad (6)$$

with $Re(Z_r)$ the real part of the radiation impedance of a breathing sphere.

Question 4

Compute the radiated power P_r in W of this sound source for f = 100 Hz and f = 1000 Hz (look in course book for Z_r formula). Can you explain the differences between the computed results?

Question 5

Compute the sound pressure level L at 100 m from this source in dB for 100 Hz and 1000 Hz (without the effect of air attenuation).