Task 4

Sound power measurement using sound intensity

4.1 Task

1. Measure sound power of selected source of noise using sound intensity
2. Study behavior of sound intensity measured by p-p probe

4.2 Theory

4.2.1 Sound power

One of the possible sound power measurement methods is based on measurement of sound intensity and application of following integral

$$W = \oiint_{(S)} \vec{I} \cdot \vec{n} \, \mathrm{d}S \; . \tag{4.1}$$

Measurement is based on choice of appropriate surface enclosing the measured source. The most common shape of the surface is cube or rectangular parallelepiped. Integral (4.1) can be modified with respect to the fact that the sound intensity probe usually measure one-direction component only. In the case of sound power measurement we choose component normal to the measurement surface.

$$W = \oiint_{(S)} \vec{I} \cdot \vec{n} \, \mathrm{d}S = \oiint_{(S)} I_{\mathrm{n}} \mathrm{d}S \; . \tag{4.2}$$

In practice we have two possibilities how to approximate surface integral (4.2). The first is called measurement in points and it is illustrated in figure 4.1a. In this case the surface integral is replaced by the summation:

$$W \approx \sum_{i=1}^{N} I_{\mathrm{n}i} S_i \; , \tag{4.3}$$

where $I_{\mathrm{n}i}$ is the normal component of the sound intensity in the ceter of each surface element S_i and N is the number of elements.

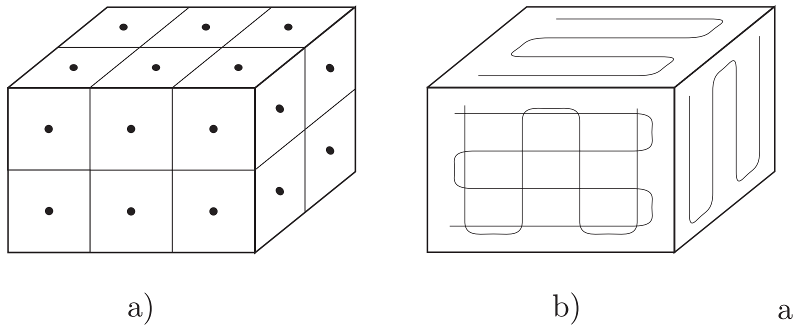
The second method of approximation of the integral (4.2) is based on the assumption that each of the surfaces could be divided into the strap of constant width D and the probe is moving in the middle. Possible tracks are depicted in figure 4.1b. Surface element can be replaced by $\mathrm{d}S = D\mathrm{d}l$, where l is the track element and integral (4.2) can be rewritten in the form

$$\int_{(S)} I_{\mathrm{n}} \mathrm{d}S \approx \int_{(l)} I_{\mathrm{n}} D \mathrm{d}l = D \int_{(l)} I_{\mathrm{n}} \frac{\mathrm{d}l}{\mathrm{d}t} \mathrm{d}t = D \int_{0}^{T_s} I n v_s \mathrm{d}t \; . \tag{4.4}$$

Under the assumption that the speed of probe movement is constant it can be expressed as $v_s = l/T_s$ and taking into account that $Dl = S$ we have

$$W \approx S\frac{1}{T_s}\int_0^{T_s} I_{\mathrm{n}}\mathrm{d}t\ . \tag{4.5}$$

From this integral follows that time integration performed during the scan is also integration over the measuring surface. This method is called *Scanning method.*



Obrázek 4.1: Approximation of the surface integral for sound power measurement by sound intensity for a) measurement in points b) scanning method

If one of the surfaces is totally reflecting (hard wall) the normal component of the sound intensity is zero and contribution to the surface integral is also zero. In this case this surface is not taken into account. In practice, concrete floor is sufficiently hard.

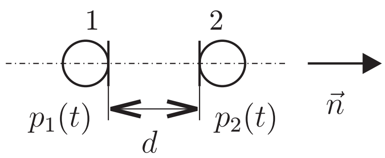
Sound power could be also expressed in the form of sound power level

$$L_W = 10\log\frac{W}{W_0}\ , \tag{4.6}$$

where $W_0 = 10^{-12}\,\mathrm{W}$.

4.2.2 Sound intensity measurements

At present the most common sound intensity probes are based on sound pressure measurement in two adjacent points (see Figure 4.2) usually called *p–p* probe or two-microphone probe.



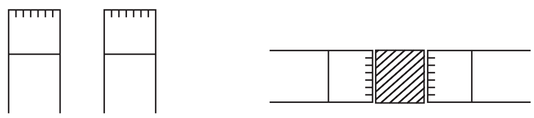
Obrázek 4.2: Two-microphone probe

For sound intensity measurements using *p–p* probe it is necessary to use high quality condenser microphones that can be arranged in several ways. The most common arrangement is face to face with hard spacer between cower grids of the microphones. The spacer is not only for precise setting of the distance between microphones but also for improvement of phase characteristics of the probe.

Maximal phase matching between both microphone channels is the basic requirement for good accuracy of the probe. If the probe is placed in the plane wave sound field in the way that the probe axis is parallel to the direction of sound propagation, the sound intensity level L_{I_n} will (numerically) be equal to the sound pressure level L_p (under assumption that $I_0 = p_0^2/\rho c$). In ordinary sound field the difference between sound pressure level and sound intensity level is called *pressure-intensity index* or simply *p-I* index.

$$\delta_{pi} = L_p - L_{I_n} \; . \tag{4.7}$$

If the probe is placed in the plane wave sound field in the way that the probe axis is perpendicular to the direction of sound propagation, sound intensity component equals zero and sound intensity level should be minus infinity[1]. In real measurement we measure level differing of tens of decibels. This is due to mismatch between the channels that is evaluated as non-zero pressure gradient by measuring system and it results in „residual intensity“. Difference between sound pressure and sound intensity levels we denote δ_{pI_0} and call *residual intensity index.* This index characterize dynamic capabilities of the system.



a) b)

Obrázek 4.3: Arrangement of condenser microphones in intensity probe

Two-microphone method has several limitations that follows from used approximations. The most important is the limitation on both low and high frequencies that are related to the particle velocity approximation. For low frequencies the estimate of sound pressure gradient is influenced by phase matching between the channels (see figure 4.3a). For low frequencies or long wavelength the phase difference is masked by phase error. Limitation on high frequencies is seen in figure 4.3b and we require approximately $\lambda > 6d$ in practice. Intensitometers can express not only sound intensity level but also orientation of intensity vector. Sound intensity level is defined

$$L_I = 10 \log \frac{I}{I_0} \; , \tag{4.8}$$

where it is impossible to include the fact that the intensity could be negative. Therefore it is usually expressed by the minus in the brackets behind the value of the level (e.g. $L_I = (-)75\,\mathrm{dB}$).

[1]Sound intensity is generally equal zero in all places where is no transport of energy, eg. in standing waves or diffuse sound field where time average of sound energy transport equals zero.

4.3 Measurement procedure

1. Create imaginary measuring surface in the form of cube $1\times1\times1$ m. Every surface of the cube (except the floor) divide into four equal sections (small squares) and enumerate them properly.

2. Execute auto-ranging in one measuring point when the source of noise is switch on (the first or upper button on the probe remote control).

3. In the middle of each sub-surface measure normal component of the sound intensity (start by the fourth button, measurement takes 8 s). Reasonable measurements store (the second button).

4. Evaluate the third-octave spectrum of the noise source sound power.

5. Calculate total radiated sound power (in Watts).