Task 6

Measurement of reverberation time

6.1 Task

Measure reverberation time in third-octave bands using interrupted noise method and impulse excitation method. Present results in graphs.

6.2 Theory

Reverberation time is the basic acoustic parameter characterizing the space. Reverberation time is defined as the time required for the sound pressure level to decrease by 60 dB that corresponds to the time in which the sound energy density falls to 10^{-6} of its initial value.

According to the Sabine's assumptions following reverberation formula can be derived

$$T_{\mathrm{S}} = 0{,}164 \frac{V}{\alpha S} \;, \tag{6.1}$$

where V is room volume, S is surface of the walls and α is sound absorption coefficient.

Sound absorption coefficient α characterize average absorption of all surfaces of the enclosed space (room). In usual room absorption coefficient is not unique and if the particular surface S_i has the particular absorption coefficient α_i then the average coefficient is done by expression

$$\alpha = \frac{\sum_i \alpha_i S_i}{S} \;, \tag{6.2}$$

where total surface of the space S equals to the sum of all subsurfaces S_i.

Sabine's equation (6.1) has a limited validity. For totally absorptive walls ($\alpha = 1$) reverberation time is evidently nonzero though it should be zero. This inconsistency was corrected by Eyring who derived improved reverberation formula in the form

$$T_{\mathrm{E}} = 0{,}164 \frac{V}{-S \ln(1-\alpha)} \;, \tag{6.3}$$

However, for the spaces with average sound absorption $\alpha < 0{,}2$ and not too big differences between individual surfaces the Sabine's formula gives approximately the same results as Eyring's formula.

Both formulas (6.1) amd (6.3) are incorrect when $\alpha \to 0$ as reverberation time should tend to infinity. However sound does not propagate without losses. We have to take into account sound attenuation (caused by energy dissipation in air) that results in exponential decay of sound intensity with distance

$$I = I_0 \mathrm{e}^{-ml} \;, \tag{6.4}$$

where I_0 is initial sound intensity and m is a sound attenuation coefficient. Introducing this fact into Sabine's formula we obtain

$$T_{\mathrm{S}} = 0{,}164 \frac{V}{\alpha S + 4mV} \;, \tag{6.5}$$

where sound attenuation coefficient m takes values from $0{,}001\,\mathrm{m}^{-1}$ to $0{,}06\,\mathrm{m}^{-1}$ depending on frequency and relative humidity. The Eyring's formula can be corrected by $4mV$ identically.

Reverberation is connected with reflections in enclosed space therefore it can be assumed that reverberation time will be related to impulse response of the room. This idea was developed by Schoeder in sixties and it results not only in „new“ reverberation time calculated from this impulse response but also other objective room acoustics parameters. Let us assume that the room is excited by acoustic Dirac pulse[1], then from the time record of sound pressure $p(t)$ (impulse response) in a point we can determine reverberant decay of sound energy

$$E(t) = \int_t^\infty p^2(\tau)\mathrm{d}\tau = \int_0^\infty p^2(\tau)\mathrm{d}\tau - \int_0^t p^2(\tau)\mathrm{d}\tau \,. \tag{6.6}$$

Introducing the notation

$$E_t = \int_0^t p^2(\tau)\mathrm{d}\tau \,, \tag{6.7}$$

we can derive sound pressure level decay corresponding to reverberation decay in the form

$$D(t) = 10 \log \left(1 - \frac{E_t}{E_\infty} \right) \,, \tag{6.8}$$

where 0 dB corresponds to status of fully excited room.

6.2.1 Measurement of reverberation time

Reverberation time is defined to be the time for the sound pressure level to drop by 60 dB after the sound source is interrupted. To be able to measure such a decay it is necessary to have sound pressure level before interruption of the source more then 60 dB higher then background noise level. It is not always possible therefore it is possible to evaluate time of 30 dB drop and take this time twice (or 20 dB decay time taken three times).

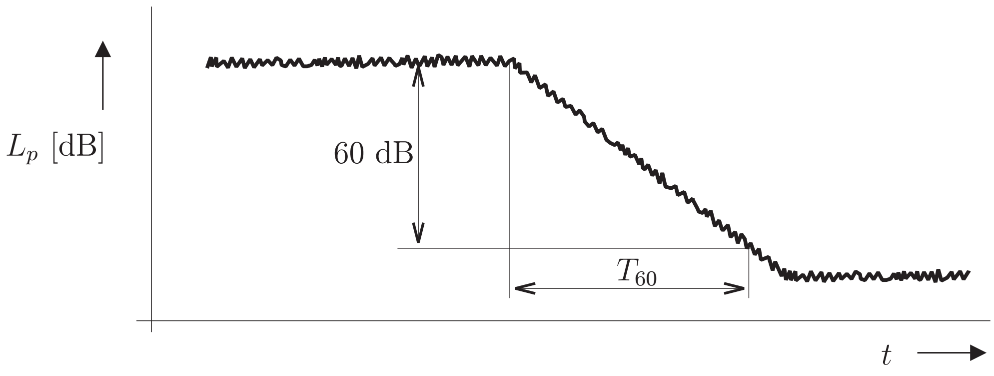
Provided that the room is excited by wide-band noise (usually pink noise) measurement method is called interrupted noise method and decay curves (for each frequency band) can have a shape similar to that in Figure 6.1.

Reverberation time is usually measured for third-octave frequency bands from 100 Hz to 5 kHz or actave bands from 125 Hz to 4 kHz[2]. According to the international standard sound pressure level drop is evaluated from -5 dB to -35 dB with respect to excitation level.

The second measurement method is called integrated impulse response method and it is based on equations from (6.6) to (6.8). It assumes that the room is excited by acoustic impulse but realization of sufficiently high and narrow pulse is relatively demanding. Dirac

[1]Note that realization of Dirac pulse in acoustics is more complicated than in electrotechnics. Therefore in practical realization we profit from known relation between Dirac pulse and unit step that is followed by MLS signals and other techniques.

[2]It is possible to excite the room subsequently by third-octave (or octave) band noises or use pink noise in whole frequency band. The latter case is more rapid but it is more difficult to ensure enough of sound energy in each frequency band.



Obrázek 6.1: Example of decay curve from reverberation time measurement

pulse is usually approximated by gunshot, electric discharge or burst of a toy rubber balloon. These days the most common approach is based on usage of MLS (Maximum Length Sequence) signals. Room response to this signals can be transformed into impulse response and then using equation (6.8) and digital filtration we can acquire decay curves for individual third-octave bands.

6.3 Measurement procedure

1. Use B&K PULSE system for reverberation time measurement. Measurement is performed for two microphone positions (simultaneously). Use wide-band pink noise signal covering whole measured frequency band.

2. Measure reverberation time using impulse source with the same arrangement. Use alarm gun as a source of impulse sound.

3. Compare both results.

6.4 List of equipment

- B&K PULSE, typ 2825
- microphones B&K, typ 4190
- amplifier DENON, PMA-655R
- loudspeakers B&W