<u>Technical Acoustics and Noise Control</u> *(lecture notes)*

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Content:

13.1. Introduction to noise control, subjective measurement units (lecture notes)

In today's world, one of wide spread harm to human health is the environmental noise pollution. Disturbing expose to noise can take place in the residential area during resting time or in workplace too. But loud events using sound reinforcement during relax time (such as concerts, movies or dance), are at risk for the hearing too. The increased noise exposure will exhaust the hearing, cause a general tiredness and over a critical level could cause permanent hearing loss and other bad health effects. Considering the special personal, physical and legal aspects of the noise, in most of the countries the noise regulations are summarised in separate orders.

The concept of noise: The word noise has several meaning. From environmental pollution point of view the noise is a sound, disturbing the living, specifically the human organism. In this sense, the most important characteristics of the noise are, the form of environmental pollution, local and direct, civilisation problem, and there is no permanent remain in the inorganic environment.

The noise pollution is a type of environmental pollution. The undesired sound radiation is similar to pollute the air with dust, or the water with oil, or the soil with chemicals. The extreme noise level is dangerous for the human organism. To moderate these effects to an acceptable level is the goal of the noise control, and that is an important part of the environmental protection.

The noise usually a local problem. The effect of a noise source operating in a building, generally limited to the neighbouring rooms, but not more than the complete block of building. The same in free place means few hundred meters, but for a very powerful sound source the disturbing effect will sensible within a few kilo meters. Against this, for example in case of air pollution the environmental damage will be observable over hundred kilo meters from to origin of the pollution.

The disturbing noise will effect only instantaneously, and will not conserve in the living or non-living environment. Against this for example oil pollution in the sea will rest and making harm in the water till remove or decompose.

The noise is a typical problem of the civilisation. Considering the concentrated living area in towns, where the most important noise control method, to keep enough distance from the source, cannot fulfil. And the noisy technical devices, making our life easier, have strong relation with the technical development and civilisation.

After a noise event usually there is no permanent remain in the inorganic environment. Against this the noise in the living organism can cause limited period (relaxing and healing) and permanent (not relaxing and not healing) hearing damage, observable by subjective (sense) and objective (measurement device) methods as well. (e.g.: the increase of threshold of hearing).

The effect of the sound on humans: The sound is an inseparable part of the human life. Concerning the speech and hearing communication, the musical experience and the disturbing noise, that mainly effect the human organism trough the hearing. There are useful and pleasant sounds, but we cannot separate us from disturbing noise. It is important to understand that the auditory organ and the nerves system will be exhausted by sound radiation, independently from the useful or disturbing character of it. Of course the subjective opinion are better for useful and pleasant sounds than disturbing noise. To measure the exhaust effect of a sound we have to take into consideration objective (depending on the physical character of the sound) and subjective (depending on listener person) factors. Among the objective factors the most important are the immission sound pressure level and the radiation time. Among subjective factor the activities, life situation and health conditions are important. The sound has health effects not only through hearing, but we will not go into details in this brief introduction.

Noise evaluation indices: A basic exercise in noise control to measure the magnitude of the noise, compare to the limitation and if it is reasoned to reduce the noise to an acceptable level. Because of this, it is required some noise indices that can characterise the noise safely. The subjective opinion of a noise effected by objective (measurable physical quantities) factors and subjective (depending on the annoyed person) factors together. The objective factors (e.g.: sound pressure level, frequency) that can measure or calculate, will be described by noise indices. The subjective factors will take into consideration by scales of limit and criteria values. This means, that for different life activities and situation belong different limit and criteria value, prescribed in orders

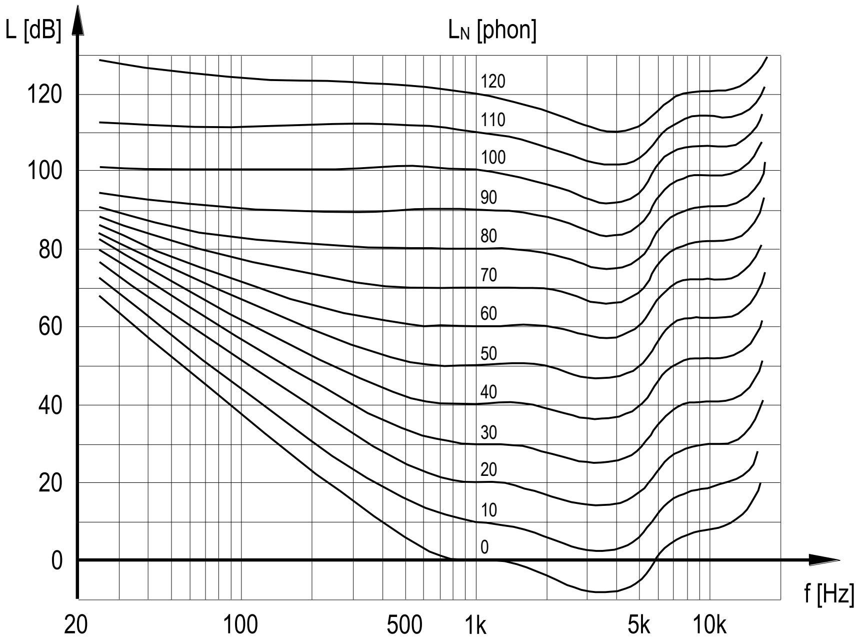
Objective factors effecting the subjective opinion of a noise: General practise that short time and low level noise is more acceptable than long term, high level one. The most important two physical variables effecting the subjective opinion of a noise are the sound pressure level and time of the sound radiation, together the noise exposure. Over these two variables, the frequency, the spectrum, the time history and the elevation from the background will effect our subjective opinion.

Noise exposure: The noise exposure (ΔW, noise dose) is the exhausting work on auditory organ carried out by the noise. The noise exposure is the product the noise power incident to the outer auditory channel (P_n) and the radiation time (Δt),

$$\Delta W = P_n \Delta t = I_n A_{ac} \Delta t = \frac{p_{eff}^2}{\rho_0 a} A_{ac} \Delta t = \frac{A_{ac}}{\rho_0 a} p_{eff}^2 \Delta t \sim p_{eff}^2 \Delta t$$

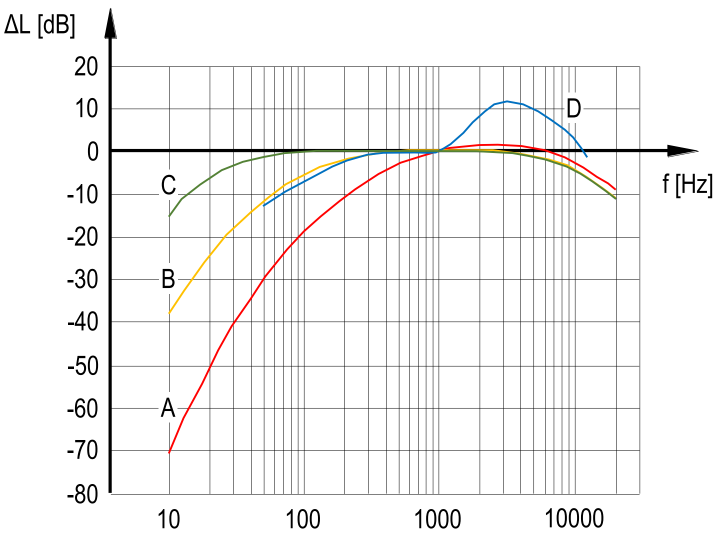
The noise exposure is analogous phenomena to the light exposure applied in photography. The sound power enters the outer auditory channel is the product of the noise intensity (I_n) and cross sectional area of the auditory channel (A_{ac}). Suppose, that the sound, enters the ear is a free plane wave, the intensity can write as the ratio of the effective sound pressure (p_{eff}) square and the product of the equilibrium density and sound speed ($\rho_0 a$). Usually the air, that transmits the sound is close to the technical normal state (p_0=1bar, t_0=20ºC) and the cross sectional area of outer auditory channel for different people are not extremely different, so the ratio ($A_h/\rho_0 a$) can approximate as constant. Based on practical consideration the effective sound pressure square expressed in level. So the noise exposure will be determined by the sound pressure level (or the sound pressure level time average) and the radiation time together. (The concrete calculation see later.)

Frequency dependence: For a healthy person the audible frequency range is approximately between 20…20000Hz. Inside this borders the sensitivity of the ear will vary on frequency. The variation of the sensitivity means that to keep equal loudness for two different frequency sound, the sound pressure level will differ to each other. The frequency variation of the human ear can characterise with the „Fletcher-Munson" equal loudness level curves (published in 1933). **Loudness level:** The loudness level of a sound is the sound pressure level of the 1kHz pure tone sound of the same loudness. The notation of the loudness level is L_N, and measurement unit is phon. The next figure will show series of constant loudness level curves, the sound pressure level variation on frequency to keep constant loudness. For example to keep the loudness of a 1kHz frequency 40dB sound pressure level at 40phon loudness level, for a sound at 80Hz frequency the sound pressure level have to increase to 65dB approximately. The equal loudness level curves were determined for poor tones, in free field and for steady sound. The mathematic operation with loudness levels is quite complicated (will not follow the algebraic and level operation rules as well).



Equal loudness level curves (by Fletcher and Munson, in 1933)

Based on this limits, it is needed a noise evaluation indices that take into consideration the human ear's frequency variation on sensitivity and easy to handle. These are the A, B, C and D weighted sound pressure levels. In accordance with the change of sensitivity the weighting curves decrease the sound pressure level in low frequency (where the ear is not sensitive), slightly increase or not change in mid frequency range (where the ear is sensitive) and decrease again at high frequency (where the ear not sensitive again). The "A" curve belongs to the low loudness level section (with strong frequency variation), the "B, C, and D" following each other to the increasing loudness (and more balanced frequency variation).



The A, B, C and D weighting curves as a function of frequency

The calculation of the weighted sound pressure level will carry out in octave or one-third octave band resolution. The A, B, C and D weighted sound pressure levels, shortly the A-, B-, C- and D-sound pressure levels will be noted as (L_A, L_B, L_C and L_D), and the measurement units are dB(A), dB(B), dB(C) and dB(D). Today the A-sound pressure level and C-sound pressure levels are in everyday use.

A-sound pressure level: The calculation of the A-sound pressure level (L_A) in octave band resolution,

$$L_A = 10\,lg\sum_{i=1}^{n} 10^{0.1(L_{okt\,i} + \Delta L_{Aokt\,i})} \qquad [dB(A)]$$

The (ΔL_{Aokt}) weighting relative levels can find in the following tabulation. (The relative levels for B-, C- and D weighting can find in related standards and textbooks.)

f_{oct} [Hz]	31.5	63	125	250	500	1k	2k	4k	8k	16k
ΔL_{Aoct} [dB]	-39.2	-26.1	-16	-8.6	-3.2	0	1.2	1	-1.1	-6.5

Relative levels for A-weighting (ΔL_{Aoct}) as a function of octave band center frequencies

Equivalent sound pressure level: In practise most of noises are non-steady (varying in time). The equivalent sound pressure level of a non-steady noise is the constant sound pressure level causing the same exhaust on the auditory organ than the non-steady noise event, during the same exposition time. The equivalent sound pressure level is a single value indices to characterise the non-steady noise event. The calculation for the equivalent A-weighted sound pressure is,

$$L_{Aeq}=10\,lg\left(\frac{1}{t_m}\int_0^{t_m} 10^{0.1L_A}dt\right) \qquad [dB(A)]$$

Where ($L_A(t)$) is the time function of the A-sound pressure level, (t_m) is the measurement time. If the complete measurement time of the noise build up with constant noise level time sections, the integral can replace to a summa expression

$$L_{Aeq}=10\,lg\left(\frac{1}{t_m}\sum_{i=1}^{n}\Delta t_i 10^{0.1L_{Ai}}\right) \qquad [dB(A)]$$

Where (n) is the number of the different constant A-sound pressure level sections, (Δt_i) is time duration of the i-th noise section and (L_{Ai}) is the A-sound pressure level of the i-th noise section.

Time history: The subjective opinion of a noise parallel with the exposure and frequency will depend on time history of the noise too. Practical experience that the slowly increasing, constant and slowly decreasing noise events are more acceptable than the impulsive (gunshot) or sound with periodic level variation (ambulance car siren). The extra disturbing effect of the impulsive noise will be considered with a correction in the rated noise level.

Spectrum: The shape of the noise spectrum will effect the subjective opinion of a noise too. The subjective opinion of a spectrum with tonal (highly elevated frequency) component (that sounds rumbling or whistling) is worse than a noise with flat spectrum. The bubbling water or the wind radiate sound with flat spectrum. The extra disturbing effect of the tonal noise will be considered with a correction in the rated noise level.

Rated noise level: The rated noise level (L_{AR}) used to evaluate the environmental community noise. The rated noise level is the sum of the equivalent A-weighted sound pressure (L_{Aeq}) and four correction factor. The inspection time of the equivalent A-weighted sound pressure in day time period is 8 hour, at night 0.5 hour.

$$L_{AR}=L_{Aeq}+K_b+K_e+K_t+K_i \qquad [dB(A)]$$

Where (K_b) is the background noise correction, (K_e) is the unfurnished, empty room correction, (K_t) is tonal correction and (K_i) is the impulsive noise correction. The (K_b and K_e) corrections retake measurement problems, the (K_t and K_i) corrections consider subjective effects for the evaluation.

13.2. Test questions and solved problems

T.Q.1. What is noise, what are their most important characteristics, and give example to its health effects! (See lecture notes!)

T.Q.2. Define the phenomena of equivalent sound pressure level, and give the related calculation methods! (See lecture notes!)

T.Q.3. What is the rated noise level, what it is used for, and list related correction factors! (See lecture notes!)

S.P.1. The octave band spectrum of a noise was determined on site measurement. Let calculate the A-sound pressure level of the noise! The octave band sound pressure levels (L_{oct}) and the relative levels of A-weighting (ΔL_{Aoct}) as a function of the octave band center frequencies (f_{oct}) can find in the next tabulation.

f_{oct} [Hz]	31.5	63	125	250	500	1k	2k	4k	8k	16k
L_{oct} [dB]	80	90	90	80	70	60	60	50	50	40
ΔL_{Aoct} [dB]	-39.2	-26.1	-16	-8.6	-3.2	0	1.2	1	-1.1	-6.5

Solution:

f_{oct} [Hz]	31.5	63	125	250	500	1k	2k	4k	8k	16k
$L_{oct} + \Delta L_{Aoct}$ [dB]	40.8	63.9	74	71.4	66.8	60	61.2	51	48.9	33.5

$L_A = 10lg(10^{4.08} + 10^{6.39} + 10^{7.4} + 10^{7.14} + 10^{6.68} + 10^{6} + 10^{6.12} + 10^{5.1} + 10^{4.89} + 10^{3.35}) \approx 76.9$ [dB(A)]

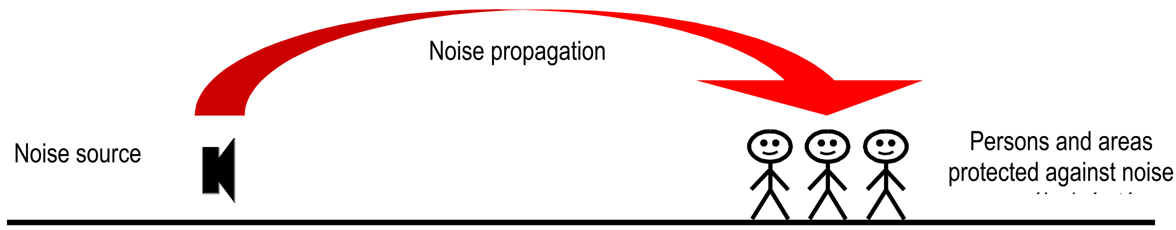
S.P.2. The noise radiation to a worker during the performance of his duties in a factory can share into three section as, 3 hour 65dB(A), 1 hour 70dB(A) and 4 hour 55dB(A) time and A-weighted sound pressure. Calculate the worker's A-weighted noise exposure for 8 hour rating time ($L_{AEX,8h}$)!

Solution:

$$L_{AEX,8h} = 10lg\left((1/8)\sum_{i=1}^{n} \Delta t_i 10^{0.1 L_{Aeqi}}\right) = 10lg\left((1/8)\left(3\cdot 10^{6.5} + 10^{7} + 4\cdot 10^{5.5}\right)\right) = 64.1\ dB(A)$$

14.1. General survey of the noise control methodologies (lecture notes)

Basic exercises of the noise control are to determine the noise exposure, evaluate the results and if it is reasoned to reduce it to an acceptable level. Noise control problem can appear for example at the design of a new device, or at a noisy machine installed in urban area close to living houses.



The general process of the noise conflict formation

General methodologies of noise control: All noise conflict need noise sources, noise propagation and protected area with protected persons. This division can apply to classify noise control methodologies too.

Noise control by reducing the radiated sound power: Primary method in environmental protection to reduce the emission of the disturbing source. This is true for acoustics as well. In the following section we list some examples for the reduction of the radiated sound power,

- Modification of the base process: Generally the noise is an undesired side effect of a useful main process. Modifying or reducing the power of the main process, sometime allow to reduce the radiated noise too. For example a dull (not sharp) sheet metal cutting machine in operation need big cutting force. The big force results big deformation and at the end of the process a loud sound effect. In this case sharpen the cutting tool will result more silent operation. Traffic noise can reduce when a small portion of ware is not transported by big truck. In air conditioning to control the volume flowrate of the ventilated air the rotational speed variation of the fan is better than throttling from noise control point of view as well.

- Reducing mechanical noise sources:

- Eliminating the cause of vibrations and impulse forces
- Avoid shocks, collisions, supply smooth rolling surfaces
- Static and dynamic balancing of rotors
- Isolate from each other the excitation and radiator surfaces
- Application of high mass and rigidity construction in the design of mechanical equipment
- Application of bigger internal attenuation materials for machines
- Use appropriate lubrication and energy absorbers
- To perforate the large radiator surfaces
- To elimination the mechanical resonance

- Reducing flow noise sources:

- To reduce the characteristic speed of the flow
- Avoid the fluctuating volume flowrate
- To keep a steady, undisturbed, smoot flow along the surface of solid bodies
- Prevention of the formation of mixing zones and shear layers
- To avoid high speed free jets, throttle valve control, and high flow turbulence
- Prevent flow separation, cavitation and shock waves
- Keep out self-excited flow processes
- To avoid structural and acoustic resonances generated by periodic fluid flow

- Reducing thermal noise sources:

- Ensure conditions with steady heat release
- To keep steady fuel and air supply and appropriate mixture of them
- Prevent unstable flames and explosions
- If possible, to use a laminar flame instead of a turbulent flame
- Prevent engine knocking
- To avoid thermally excited resonances

Noise control by preventing sound propagation: If the sound power radiated by the noise source cannot be reduced, the noise protection can also be solved by preventing the propagation of sound wave. We distinguish methods that can be used in open space, in a bounded space or in pipes, but there will also be methods that are efficient in several cases. Devices and possibilities for noise control by preventing sound propagation,

Noise control in free space:

- Increase the distance from the sound source
- Select the preferential radiation direction (for spatially varying radiation direction characteristics)
- To build up noise protection wall (noise barrier artificial or natural)
- The application of noise protection cover and hood or to build up noise protection machine housing

Noise control in space bounded with walls (with internal sound sources):

- At direct sound field dominancy: Increase the distance from the source, select the preferential radiation direction, to apply noise protection screen
- At reverberated sound field dominancy: To increase the room constant (increase the internal surfaces and sound absorption) to apply noise protecting screens and extra absorbing elements
- Independent from the direct or reverberated sound field: Noise protection cover, hood and machine housing or to separate the noise source from the protected part of the room with wall

Noise control in space bounded with walls (with external sound sources):

- To increase the transmission loss of the wall between the source and the protected area
- To increase the room constant (internal surfaces and sound absorption) in the receiver room

Noise control in ducts and channels:

- To increase the distance from the source (in the case of sound absorbing wall ducts) at low flow speed
- Insert duct elements to block sound propagation (e.g.: elbow, filter) at low flow speed
- To insert absorber or reactive type duct silencer
- To insert duct compensator to reduce the structure borne sound propagation in the duct wall

Noise control with personal protection: There are some cases when to reduce the radiated sound power and to prevent the noise propagation is not possible within acceptable technical circumstances. In this case the noise control will be ensured by personal protection. For example in a turbine hall of a power station during the daily periodic inspection, the radiated sound power of the turbines cannot be reduced, and it is impossible to insert a noise protecting hood between the source and observer. The noise protection for the persons, participating the inspection will be ensured by ear protecting pug or muff. Tools and possibilities for personal noise protection,

- Personal noise control devices (ear plug and ear muff)
- The limitation of the noise exposure by time schedule (appropriate long silent and noisy periods during working time)
- Noise isolated control rooms, and rest room.

14.2. Test questions

T.Q.1. Describe the three main class of the noise control methodologies, and give examples for each!

T.Q.2. Describe devices and possibilities for personal noise protection!
