Determination of structure-borne noise based on the vibration signal

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Introduction

In the scope of legal regulation of structure-borne noise and vibration to protect persons in buildings [1], determination takes an important part. To determine the sound pressure level a semi empiric method is applied which is based on oscillation velocity [2]. Further methods are e.g. the classical method by means of determination of the acoustic attenuation of a building structure or a method dealing with calculating the correlations with following separation of incoherent terms.

The situation is shown in figure 1. Vibrations e.g. from a railway propagate via the ground to the building. Propagation inside the building is influenced by the type of vibration and especially by the dynamic properties (phenomenon of resonance) of the building. A building structure transmits vibrations to the surrounding medium (the air) as structure-borne noise.

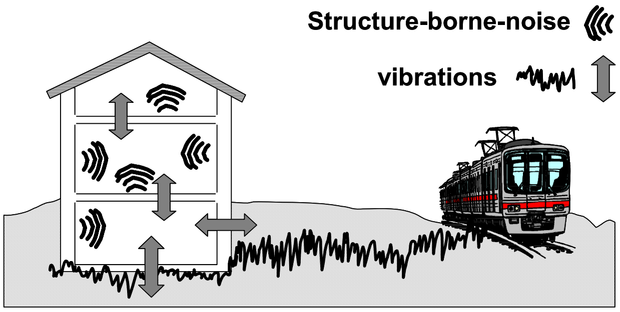

Figure 1: Situation how vibrations are influencing buildings.

The radiation properties of the room boundary (construction of the structure) as much as the properties of a reverberation chamber (the size of the room and the acoustical properties) are relevant and responsible for the radiation characteristic.

Determination of the structure-borne noise on the basis of a vibration signal, has the following advantages:

- no problems with level variation in different positions of the microphones;
- no need to separate the structure-borne noise from primary noise (outdoor noise) or noise from other sources;
- no problems with standing waves in a room.

In order to take measures against structure-borne noise, one needs to know the vibration properties.

Fundamentals of radiation

Bending waves of room boundaries result in noise emissions due to the direct contact between the surfaces and the air. Noise radiations from infinite or limited plates are described in Cremer & Heckel [3]. For frequencies lower the critical frequency, the radiation level declines substantially. In the near field the movements of the air particles lead to a hydrodynamic short circuit. In the far field there exists a radiation depending on the direction of propagation.

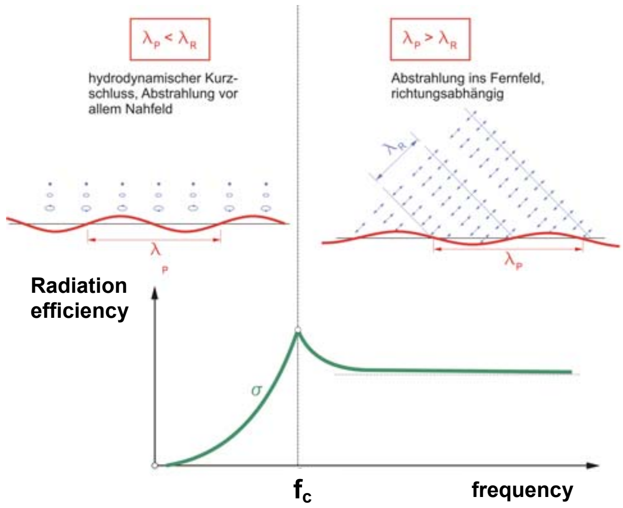

Figure 2: Critical frequency f_c
λ_P = wave length of a bending wave on the room surface
λ_R = wave length of sound in a room

Acoustic radiation efficiency σ of a vibrating object to the adjacent room:

$$\sigma(f) = \frac{S_{pp}(f)}{(\rho c)^2 \cdot S_{vv}(f)} \cdot H_R(f) \; ; H_R(f) \approx A^*(f)/4S \qquad (1)$$

$S_{pp}(f)$	power spectrum of the radiant sound pressure
$S_{vv}(f)$	power spectrum of the vibrating velocity on the building structure
c	wave propagation velocity
ρ	density of the acoustic medium (air)
$H_R(f)$	describes acoustic properties of a room
$A^*(f)$	absorbing area of a room
S	radiant surface

Transformation of the above formula shows the relation of a vibration e.g. on a floor and the sound pressure level:

$$L_{p,KS} = \sum_{f_{TB}}^{\oplus} \left(L_v(f) + 10 \cdot \log \sigma(\mathrm{f}) + 10 \cdot \log \frac{4S}{A^*(f)} + LA(\mathrm{f}) \right) \quad [\mathrm{dB(A)}] \qquad (2)$$

Radiation properties of room boundaries and acoustical properties of a room shall be characterized with one transform or transfer function H(f) = F{σ(f), 4S/A*(f)}.

Experimental studies led to a number of different characteristic types of real rooms.

Rating procedure

Structure-borne noise M is determined as rating levels M_r und M_{max} resulting from a vibration signal $v_e(t)$ by means of numerical procedures or direct measurement if there is no noise that should not be measured.

Requirements for the vibration signal $v_e(t)$: The basic quantity is the vibration signal $v_e(t)$ during the single immissions. M_r is determined during five seconds or a multiple of five seconds. M_{max} is only applied for immissions from road or rail traffic at night. The time for determination is five seconds during maximum immission level.

Transformation in the frequency domain: In order to determine M, the signal $v_e(t)$ has to be transformed in the frequency domain for further treatment. Signal $v_e(t)$ of a single immission during T_j has to be treated by Fourier-Transformation into the frequency domain. An energy equivalent power spectrum $S_j(f)$ has to be determined and thereof a third octave band power spectrum $S_j(f_{TB})$ for third octave bands from 20 Hz to 315 Hz (Sum of the amplitudes of the narrow band spectrum within the according third octave band).

Rating in a frequency range: Out of a third octave power spectrum $S_j(f_{TB})$ of the vibration signal $v_e(t)$ of a single immission j during T_j, the structure-borne noise m_j is determined by frequency rating. The frequency rating is performed by multiplication of the power spectrum with the rating functions. Structure-borne noise m_j results as sum of third octave band values. There is:

$$\mu_j^2(f_{TB}) = S_j(f_{TB})\cdot H(f_{TB})\cdot C_A(f_{TB}) \qquad (3)$$

$$m_j = \sqrt{\sum_{f_{TB}} \mu_j^2(f_{TB})} = \sqrt{\sum_{f_{TB}} S_j(f_{TB})\cdot H(f_{TB})\cdot C_A(f_{TB})} \qquad (4)$$

$H(f_{TB})$ is a rating of radiation and room properties (H) and $C_A(f_{TB})$ according to spectral sensitivity curve of human hearing (A). This structure-borne noise is characterised as an acoustical rated magnitude of vibration.

Rating of Radiation and acoustical room properties (H): Radiation properties and acoustical properties of a vibrating room are summarized by a frequency dependant factor H(f). H(f) is determined in third octave bands for typical structures and materials of the room and for typical room sizes. A material dependent critical frequency f_c is also essential. Figure 3 shows typical H(f) curves.

Rating of frequency according to acoustical perception (A): A third octave band power spectrum has to be modified by an A-filter.

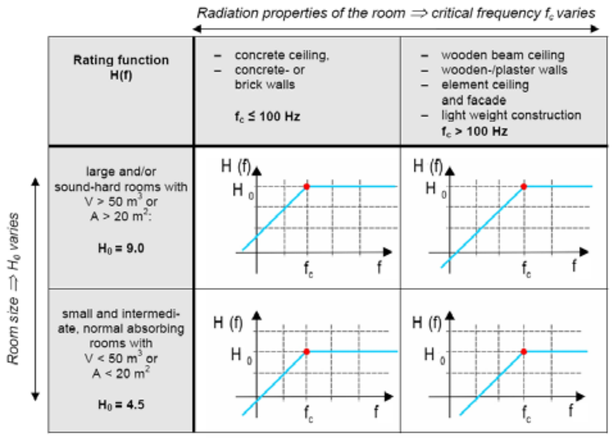

Figure 3: Diagrams for the rating function H(f) in respect to categories of objects; f_c is 100 Hz, H_o for small rooms is 4.5 and for large rooms 9.

Rating level M_r for structure-borne noise M is determined during day and night separately as follows:

$$M_r = 20\cdot\log\frac{10^{-3}\cdot(\rho\cdot c)\sqrt{\frac{1}{T_r}\sum_j T_j\cdot\left[m_j^2\right]}}{p_0} \quad [\text{dB(A)}] \qquad (5)$$

or with:

p_0	$= 2 \cdot 10^{-5}$ Pa	reference sound pressure;
ρ	$= 1.204$ kg/m³	air density at 20°C
c	$= 343.3$ m/s	sound velocity in air at 20°C
m_j	in [mm/s]	

$$M_r = 86.3 + 20\cdot\log\sqrt{\frac{1}{T_r}\sum_j T_j\cdot\left[m_j^2\right]} \quad [\text{dB(A)}] \qquad (6)$$

M_r during daytime is determined by single immissions m_j at periods T_j during T_r (T_r = 16 hours a day). M_r at night is based on the one hour with the maximum structure-borne noise m_j (T_r = one hour at night).

For road and rail traffic at night, additionally a maximum value M_{max} is determined for structure-borne noise M. M_{max} equals a level of 90% quantil of all maximum single immissions m_j per pass by during night time.

$$M_{max} = 20\cdot\log\frac{10^{-3}\cdot(\rho\cdot c)\cdot\left[m_j\right]_{90\%}}{p_0} \quad [\text{dB(A)}] \qquad (7)$$

$$M_{max} = 86.3 + 20\cdot\log\left[m_j\right]_{90\%} \quad [\text{dB(A)}] \qquad (8)$$

References

[1] Meloni T.: New Swiss regulation to protect persons from vibrations and structure-borne noise, 13th International Meeting on Low Frequency Noise and Vibration and its Control, Tokyo, JAPAN 21 – 23 October 2008.

[2] Meloni T., Billeter P., Fischer F.: Beurteilung von sekundärem Luftschall, DAGA 2005.

[3] Cremer L., Heckl M.: Körperschall, Springer Verlag, 1996.