Future prediction scheme for sound propagation from German railways

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Introduction

The present German regulation for the prediction of railway noise from 1990 [1] is no longer fully matched to the actual situation with high-speed trains and advanced procedures for noise control. Important new aspects result from the consideration of aerodynamic noise, tread brakes equipped with composite brake blocks, track maintenance including special rail grinding, and continuous slab tracks combined with special rail fasteners and acoustic absorbers. The concept for a new prediction scheme includes principles of ISO 9613-2 [2], the European interim procedure [3], and practical experience with software programs for the prediction of environmental sound impact.

Present Scheme

The present "Schall 03" [1] aimed at simplicity. It is based on utmost transparency of input data for the sound emission and on calculation schemes for sound transmission matched to generally applied procedures. Emission data are referred to results from measurements of the A-weighted equivalent sound pressure level at a reference position 25 m from the centre-line of a ballasted track, normalized for one train per hour, which is 100% equipped with disk brakes, 100 m long, and passing at a speed of 100 km/h. For such a condition, 51 dB is a typical value. Correction terms are applied for locomotives and waggon with cast-iron block brakes, wheels with absorbers, trains of different length and at different velocities, road crossings, bridges, and others. Sound attenuation due to ground effects on the propagation path is calculated according to the alternative method of ISO 9613 for A-weighted sound pressure levels. The frequency dependent sound attenuation due to atmospheric absorption and screening is approximated by typical values at 1000 Hz.

Major deficiencies result from the assumption of all source heights at rail head level, in particular from a rough approximation for aerodynamic sources at the pantograph of high-speed trains, and from the lack of distinction between wheel and rail roughness. The performance of track-side barriers and the effect of rail grinding are insufficiently rated.

Future Scheme

The future "Schall 03" shall adopt as many elements as suitable from the present one, but shall be based on

- more detailed modelling of individual sources, both in terms of their height above rail head level and their origin, e.g., rail roughness and wheel roughness, equipment noise from cooling or propulsion components and aerodynamic noise at protruding or rough components,
- description of sound sources consistent with ISO 9613-2 and the European interim procedure in terms of octave-band levels of sound power for stationary sources and for track sections with uniform sound emission and sound propagation conditions,
- a first approximation for source directivity, independent of frequency and type of source,
- a simple conversion scheme from the level of sound power per unit length, $L_{W'}$, of a line source due to one train per hour at the velocity V to the sound pressure level, L_p, at a distance d up to 25 m from the track centre-line by the relation

$$L_p = L_{W'} - 10\ \lg\left(\frac{\pi\, d}{10\ d_0}\frac{V_0}{V}\right) dB - \Delta\,, \tag{1}$$

  where $d_0 = 1$ m, $V_0 = 100$ km/h, and Δ ranges from 0,5 dB at $d = 7{,}5$ m to 2 dB at 25 m, independent of frequency,
- consideration of spherical divergence of sound waves in the propagation path from sufficiently short track sections to a receiver with excess attenuation due to atmospheric absorption and screening (dependent on frequency) and ground effects (independent of frequency),
- consideration of multi-path sound propagation involving up to three reflections,
- general consideration of weather conditions that are favourable for long-range sound propagation, but deduction of a meteorology term for the long-term average, consistent with ISO 9613-2,
- no consideration of tree zones (foliage) and of unspecified industrial sites or buildings (housing).

A major goal is the consistency of results calculated by different parties and different software programs for the same project. To that end, any ambiguity about sources and propagation paths of sound shall be avoided. There is sufficient variability in the condition of trains and tracks, of weather and ground cover, of railway operation and background noise to neglect small and unpredictable effects. But the scheme shall be open to any novel system component in terms of new sources and noise control measures.

Comparison with the European interim procedure

Similar to the Dutch specification, the future German regulation will distinguish between sound sources at various heights for

- rolling noise at rail head level or 0,2 m above,
- aerodynamic noise from the bogie areas, the roof top area and the pantograph top,
- cooling systems and traction equipment with intake and exhaust openings in the roof and bottom areas of vehicles.

Similar will also be the description of sources in terms of a specific octave-band sound power level a at a reference velocity V_0, a correction $b\,\lg(V/V_0)$ dB for the design velocity V, and further corrections c for special effects and elements, which are independent of velocity.

Additionally, distinctions will be made between powered and un-powered vehicles and between effects of rail and wheel roughness. The former is based on the experience with ICE trains of the first and second generation, which are considerably louder at both ends than in the middle, and on modern regional trains composed of three quiet waggon and a much louder loco. The latter results from the observation of rather different efficiencies of rail grinding on the sound emission from waggon equipped with cast-iron brake blocks and other braking systems. Standard measurement procedures of pass-by noise provide the single event level for complete trains only. But in view of improved future noise control, more detailed information has been evaluated.

Different from the Dutch specification are

- the reference speed of 100 km/h instead of 1 km/h, which is closer to operation conditions and avoids unusual spectral distribution functions,
- no consideration of breaking noise, switches and other phenomena related to railway stations and signals, but the assumption of a minimum train velocity, which includes contribution from the additional sound sources in such areas,
- no detailed consideration of porous ground in terms of octave-band excess attenuation, which has little effect on train noise with a maximum around 1 kHz, but unchanged application of the alternative method described in section 7.3.2 of ISO 9613-2 based on satisfactory field experience.

Background for detailed consideration of rolling noise

As long as the majority of freight waggon is equipped with block brakes and determines the rating level of railway noise due to high traffic density at night, rolling noise deserves highest attention. A simple model for rolling noise is given by eq.(2), which links the rail roughness, r_R, and the wheel roughness, r_W, to the immission sound pressure, p_i:

$$p_i^2 = \left(r_R^2 + r_W^2 + 2\,r_R r_W \cos\gamma\right) H \left(T_R \sigma_R 10^{-D_R/10} + T_W \sigma_W 10^{-D_W/10}\right) \qquad (2)$$

where $\cos\gamma = 0{,}5$ (rather than 0) denotes a correlation coefficient, which provides a slightly better match with observations of the effect of smoothing the rougher of the two contact surfaces; H is a filter function for the contact area, and the terms inside the right-hand parenthesis describe transfer functions T of vibrations, radiation efficiencies σ and airborne sound attenuations D on the propagation path via the rail (R) and the wheel (W). Since the ratio r_R / r_W of rail and wheel roughness is known from separate measurements on these surfaces for various types of braking systems (equipped with cast-iron and composite block brakes or disk brakes) and differently maintained tracks (average, after general maintenance grinding, and after "acoustic" grinding), it is possible to employ eq.(2) for splitting the total sound power determining the sound pressure square p_i^2 into a part caused by the rail roughness and another part caused by the wheel roughness. Further splitting according to the propagation paths cannot be based on separate measurements, but may be concluded from theoretical models. Such models indicate that the rail is more important for the frequency range at and below 1k Hz, while the wheel determines the higher frequencies around 2 kHz. Accordingly, wheel and rail absorbers should modify the corresponding transfer functions. However, there is no clear separation for the effect of other elements, e.g. rail fasteners and absorbing layers on continuous track beds. Consequently, the correction terms c for the effective sound power are not well separable.

It should be noted that the first two factors of eq.(2) depend on wavelength λ rather than on frequency f. The relation $f = V/\lambda$ determines the velocity dependence of sound in any frequency band. The velocity exponent b results from the slope of roughness and contact filter function vs. wavenumber as determined from measurements. The more the design velocity departs from the reference velocity, the higher is the required precision of b.

Special considerations for reflection and diffraction

In view of considerable uncertainties about the condition and composition of track and train elements, an unbalanced computational effort for propagation losses shall be avoided. To this end, reflections are restricted to vertical obstacles and diffraction to the upper edge of barriers along a railway.

References

[1] Schall 03 – Richtlinie zur Berechnung der Schallimmissionen von Schienenwegen, Information Akustik 03 der DB, 1990

[2] ISO 9613-2:1996 Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation

[3] Dutch-EU calculation scheme Railway Noise for the purpose of strategic noise mapping (RMVR 1996)