

SPECIFIC ASPECTS OF THE RAIL VEHICLE PASS-BY NOISE MEASUREMENT

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Abstract – Actual European legislative (NOI TSI) urges for quieter rail vehicles requiring obligatory assessment of noise emitted by rail vehicles within vehicle approval procedure. After survey of different rail vehicle noise emission scenarios, this paper discusses more in detail specifics of the pass-by noise measurement. The requirements of the measurement procedure from applicable standards are presented and discussed on the example of the tank wagon pass-by tests. Under several parameters that can influence measurement, for vehicle approval is important to measure and check if the most influencing parameters related to track lies in specified limits. If so, the measured noise emission level mainly represents the vehicle contribution and allows comparability to noise emission measurement of other vehicles. Two main track characteristics have to be measured and assessed: acoustical rail roughness and track decay rate. In the paper are presented both measurements that are more demanding than the noise emission measurement itself.

Keywords – rail vehicles, pas-by noise, measurement, rail acoustic roughness, track decay rate

1. INTRODUCTION

Growing public sensitivity to environmental problems, especially in densely populated areas in Europe, have led to the proliferation of noise regulations [1], [2]. One of the most challenging railway noise areas are the freight wagons. In densely populated areas in some countries, noisier wagons may be exposed to noise-differentiated infrastructure usage fees, or even banned in night trains.

Noise originated from rail vehicles has two basic aspects: noise inside the vehicle and noise emitted by rail vehicles into the environment. Noise inside the vehicle is observed from the point of view of passenger comfort [3] or exposure of train driver to noise [4].

Noise emitted into the environment has following aspects [5]:

- stationary noise (also known as parking noise),
- constant speed noise (pass-by noise),
- acceleration noise (starting noise),
- braking noise.

Every aspect of noise from rail vehicles has sources from the train movement or from the vehicle equipment operation. The train movement generates rolling noise and aerodynamic noise. Rolling noise is mainly caused by rail and wheel roughness. Further

noise generators are wheel flats, rail joints, local sources as switches, crossings, wheel squeal in curves, steel bridges etc. For high-speed vehicles, aerodynamic noise makes important noise component.

Operation of equipment on rail vehicles determines stationary and acceleration noise.

Any aspect of the noise abatement requires reliable test methods. The following consideration relates to some specific aspects of pass-by noise measurement illustrated using examples for pass-by noise measurement of Zacs tank wagon [6].

2. GENERAL CONDITIONS OF PASS-BY NOISE TEST

In order to obtain reliable, reproducible and comparable noise measurement results, it is necessary to measure significant influencing quantities and keep them within some acceptable limits. This includes acoustical neutrality of the test site, environmental conditions, track conditions and vehicle conditions.

The test track must not significantly affect the measurement of noise emitted by the vehicle and shall enable maximum test speed. The test section should be straight or with big radius, shall have a consistent superstructure over a minimum length of twice the microphone distance to either side. This includes

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geometry of the line, track quality, acoustic rail roughness and track decay rates.

Track superstructure should be a track with ballast bed and wooden or reinforced concrete sleepers without any type of rail or track shielding. The ballast shall be loose i.e. not bound together.

The measuring section shall be laid without rail joints, shall be free of visible defects and without audible impact due to welds or loose sleepers.

The test site shall allow free sound propagation. The level of the ground surface shall be within 0 m to -2 m, relative to the top of rail, test area shall be free of other tracks, of sound absorbing matter (snow, tall vegetation...) and free of reflective covering (water, ice, tarmac, concrete...). No absorptive material shall be added to the propagation path.

Test persons shall be in a position behind microphone that does not influence the measured sound pressure level significantly. An area around the microphones within radius at least three times the measurement distance shall be free of large reflecting objects (barriers, hills, rocks, bridges or buildings).

Meteorological conditions in normal measurement situation have relatively small influence on measurement results, so no correction of the results is required, but they can be taken into account in the assessment of measurement uncertainty.

Meteorological conditions shall be recorded: wind speed and direction at the level of the microphone, temperature, humidity, barometric pressure and precipitation. Heavy rain or wind speed higher than 5 m/s are not allowed as they may affect test results.

Two main track parameters must be measured: acoustical rail roughness and track decay rate.

3. ACUOSTICAL RAIL ROUGHNESS MEASUREMENT

The acoustical rail roughness is defined by following equation:

$$L_r = 10 \cdot \log \left(\frac{r_{RMS}^2}{r_o^2} \right) \quad (1)$$

L_r is the acoustic roughness level in dB,
 r_{RMS} is the root mean square roughness in μm ,
 r_o is the reference roughness; $r_o = 1 \mu\text{m}$.

Measurement was performed according to the procedure given in [7] along rolling band of both rails. The rolling band can be regarded as shiny part on the head or can be determined by traces obtained by passing of the tested wagon over the artificially colored part of the railhead. Referent width w_{ref} is 5 mm narrower at each side than rolling band, as shown in figure 1, taking into account that typical wheel-rail contact is approximately 10 mm wide.

Position of the central line of referent surface d_{ref} is measured from outer (not worn) surface of each rail. Roughness measurement should be performed along 1

central line if the $w_{ref} \leq 20$ mm, along three lines each 5 mm apart for w_{ref} between 20 and 30 mm and along three lines each 10 mm apart if $w_{ref} > 30$ mm.

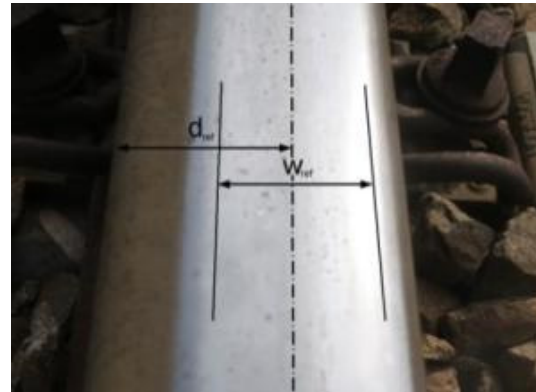


Fig. 1. Referent width of the rolling band

For the Zacns wagon test, the rolling traces were taken on beginning and on the end of the test zone. Taking into account average rolling band center position and maximum reference width, roughness measurements were made along three parallel lines 5 mm apart on each rail.



Fig. 2. Roughness measurement

Measurements were performed over the entire test section of 15 m length using device "m rail trolley", of the Müller-BBM rail technologies, Germany (figure 2), that meets requirements of [7]. Signal processing includes removal of spikes, curvature processing, that takes into account typical radius of the wheel contacting with rail and determination of 1/3 octave band spectrum for each of six samples.

The results are shown in figure 3. Lines correspond to lateral position of samples, three per each rail. For the approval of the freight wagon noise emission, the rail roughness should be below maximum limit curve shown in figure 3 as "TSI/ISO 3095:2010", in order to noise measurement results designate as comparable.

The measured values slightly exceed the upper limit. Consequently, test results of the noise emission cannot be compared to other "comparable" measurements, but are still acceptable if the measured noise level remains within limits for pass-by noise.

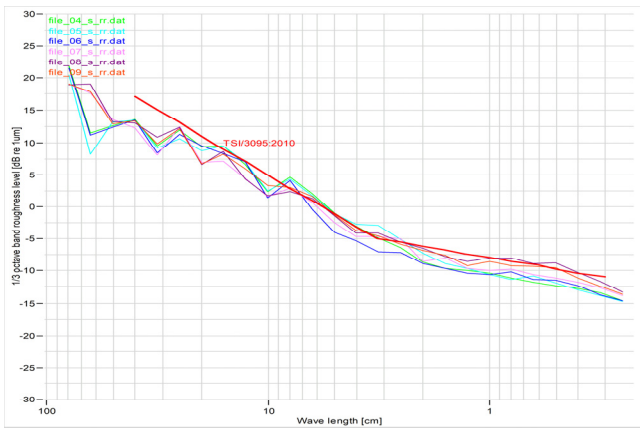


Fig. 3. Rail roughness 1/3 octave band spectra for left and right rail

4. DYNAMIC PROPERTIES OF THE TEST TRACK

The dynamic properties of the track have been evaluated in accordance with [8]. They are based on an estimate of the mechanical vibration decay rates (DR) along the rails in the one-third octave frequency band between 100 Hz and 5000 Hz. The values should lie above the lower limit curve given in [2].

The decay rates are determined on the basis of a frequency response functions (FRF) at the impulse hammer application point (direct FRF) and a certain number of FRF measurements along rail relative to the position of the excitation point (transfer function).



Fig. 4. Instrumented hammer impact for direct FRF

An instrumented hammer with a steel tip was used to excite the rail in vertical (figure 4) and transverse direction. An accelerometer fixed to the rail in the vertical and the other in the lateral direction measured the corresponding response for each direction.

First, the initial accelerometer position was sought in the middle of two sleepers near one end of the test section. Three positions were checked for each rail. If the results show similarity of the obtained direct FRFs for each impact direction, one of the three positions can be used as the accelerometer position for all measurements at one rail.

The full set of FRF was measured in the vertical and transverse directions on the right and left rails with force impact applications at various distances x

from the accelerometer across the test section, as shown schematically in figure 5.

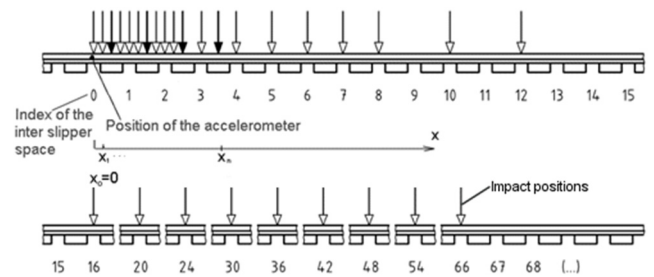


Fig. 5. Grid of the excitation points

The measurements were carried out to the point for which the response was at least 10 dB lower in each one-third octave band than direct FRF (obtained at x=0). It was necessary to make measurements up to distance $x_{max} = 21,6$ m.

An average FRF of 4 validated impulses were taken into account for each elementary FRF. The quality of each FRF measurements was checked using coherence function.

The decay rates (DR) of the vertical and transverse bending waves as a function of the distance are calculated based on these sets of FRF measurements in each one-third octave band using the following formula [8]:

$$DR = \frac{4,343}{\sum_{x=0}^{x_{max}} \frac{|A(x_n)|^2}{|A(x_0)|^2} \Delta x_n} \quad (2)$$

Here is:

$A(x_0)$ FRF at position $x=0$ (direct FRF) in regarded one-third octave band,

$A(x_n)$ FRF at position x_n along the track (transfer FRF) in regarded one-third octave band,

Δx_n – distance between the points situated at half-distance between the measuring positions on either side of the excitation position n.

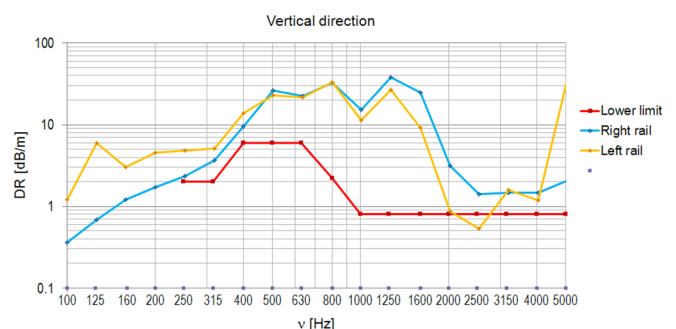


Fig. 6. Track decay rate in the vertical direction

Figure 6 shows the calculated track decay rates for left and right rail in vertical direction. In the 1/3 octave band of 2500 Hz the decay rate is below lower limit, making further noise emission test results "non-comparable".

5. PASS-BY NOISE MEASUREMENT

For the pass-by noise test was used composition consisting of locomotive, one 98 m³ Zacns tank wagon and one 87 m³ Zacns tank wagon, figure 7. These two tank wagons have identical design and only differ in length.



Fig. 7. Test composition pass measurement point

At least three measurements at 80 km/h $\pm 5\%$ and three at $v_{max} = 120$ km/h $\pm 5\%$ should be performed. The microphone is positioned at 7,5 m of track axis and 1,2 m above top of rail.

The basic measured quantities are L_{pAeq, T_p} , train speed and pass-by time T_p .

L_{pAeq, T_p} is A-weighted equivalent continuous sound pressure level given by the following formula:

$$L_{pAeq, T_p} = 10 \cdot \log \left(\frac{1}{T_p} \int_0^{T_p} \frac{p_A^2(t)}{p_0^2} dt \right) \quad [\text{dB}] \quad (3)$$

where:

T_p is the measurement time interval in s;

$p_A(t)$ is the A-weighted instantaneous sound pressure at running time t in Pa;

p_0 is the reference sound pressure; $p_0 = 20 \mu\text{Pa}$

During the pass-by of the test train the A-weighted sound pressure level was continuously measured as a function of time. Each wheel position vs. time relative to microphone, was detected using an optical sensor fixed close to the rail and aligned with microphone. From this signal, is calculated actual speed of the train and moments of passing middle of the first and second tank wagon T_1 and, which enabled integration of $L_{pA}(t)$ in time interval $T_p = T_2 - T_1$ in order to get L_{pAeq, T_p} .

The test procedure includes calibration of microphones and background noise measurement, measured at the beginning of the test, checking of acoustical neutrality of neighboring vehicle (locomotive in this case), normalization to speed of 80 km/h, and to specific wagon length per axle according to formula:

$$L_{pAeq, T_p(\text{APLref})} = L_{pAeq, T_p(v_{\text{test}})} - 10 \cdot \log(\text{APL}_{\text{wag}} / 0,225 \text{ m}^{-1}) - 30 \cdot \log(v_{\text{test}} / 80 \text{ km/h})$$

Here is: $\text{APL}_{\text{wag}} = \frac{n}{L_{OB}}$, n is number of axles, L_{OB} is

length over buffers and v_{test} is actual speed during the measurement.

Figure 8 shows an example of $L_{pA}(t)$ during the pass-by test at 120 km/h. The red line indicates the passage of each wheel of the composition.

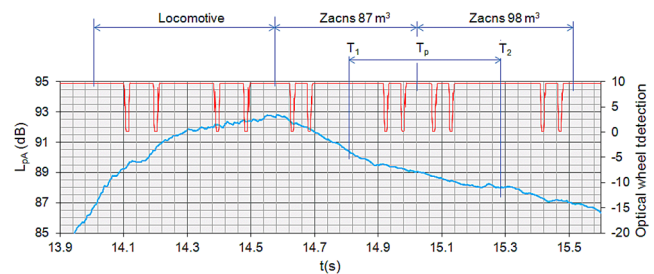


Fig. 8. Example of sound pressure level record

After normalization, for assessment, the arithmetic mean of the series of measurements is rounded to the nearest integer decibel. For the Zacns wagons, the determined value of 83 dB was right at the upper permissible limit.

4. CONCLUSION

Pass-by noise measurements of rail vehicles require careful search for the suitable test section to obtain comparable results. Poor track acoustical characteristics like track roughness and track decay rate may amplify pass-by noise beyond the allowable limits. Achieving the relevant track characteristics requires more effort than the noise measurement itself.

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REFERENCES

- [1] Directive 2002/49/EC of the European Parliament and of council of 25 June 2002 relating to the assessment and management of environmental noise
- [2] TSI Noise (Commission Regulation (EU) No 1304/2014 with amendment M1/2019)
- [3] EN ISO 3381:2005, Railway applications - Acoustics - Measurement of noise inside railbound vehicles
- [4] EN 15892:2011, Railway applications - Noise Emission - Measurement of noise inside driver's cabs
- [5] EN ISO 3095:2013, Acoustics - Railway applications - Measurement of noise emitted by railbound vehicles
- [6] Pass-by noise test report of Zacns 98 m³ tank wagon No: LSV-I-6/20 Edition 2, University of Belgrade Faculty of Mechanical Engineering, 2020
- [7] EN 15610:2009, Railway applications - Acoustics - Rail and wheel roughness measurement related to noise generation
- [8] EN 15461:2011, Railway applications - Noise emission - Characterisation of the dynamic properties of track sections for pass by noise measurements