

Measurement of the Noise Originating From Class 2 High Speed Rail Vehicles

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Summary

Due to the dynamic development of railway transport, it is necessary to supervise its impact on people and the surrounding environment. Noise is the main subject of this work, as it is the main railway transport factor that causes annoyance for the environment. Regarding increased speed railways, works are currently being conducted to find the dominant sources of negative acoustic effects. Determining the motives that cause rising of the noise sources, indexing them as well as creating an acoustic effects model for such trains should contribute to the efficient design of the means dedicated for minimizing acoustic effects. The authors have reviewed publications concerning the currently-utilized methods, described a noise assessment approach, and proposed a way to conduct field tests on real objects. A location was chosen, required permissions were obtained, sophisticated measuring equipment was collected, and pilot experimental tests were performed, with the results being described in this work.

Keywords: railway noise, increased speed railways, environmental impact

1. Introduction

In 2017, the European Environment Agency demonstrated, on the basis of reports provided by 33 Member States, that about 19 million people are exposed to noise originating from railway transport. As a result, it is clear that railway noise, just after road noise (affecting over 100 million people), is the second biggest noise source exposing people to noise over 55 dB L_{den} [4].

Railway noise has to be counted among the most annoying sources contaminating the surrounding environment. The level of noise from railway transport is influenced by many factors including, among others, the technical state of the superstructure (rails, slippers, fastening systems, ballast and railway points) as well as the technical state of the rolling stock, landform and the speed of the rolling stock, which has been recently growing.

Alstom ED250 series railway vehicles (named Pendolino) of the ETR610 type are currently the quickest ones on Polish railway lines. They are able to reach speeds of even 200 km/h. In accordance with the guidelines of the TSI Rolling Stock for high speed rail system [2], railway vehicles having a maximum speed of at least 190 km/h but less than 250 km/h are classified as class 2

high speed rail vehicles. For the purpose of this article, such vehicles are named increased speed rail vehicles.

Ongoing changes increasing the quality of runs in railway transport bring about many questions. Among others, there is a question of whether introducing newer technical solutions as well as newer rolling stock may lower noise originating from railway vehicles in respect of growing requirements regarding travelling times? Which noise source is the dominant one in the case of increased speed rail vehicles running at the speed of about 200 km/h? Is it still rolling noise or already aerodynamic noise?

It is therefore necessary to analyse the main noise sources associated with increased speed rail vehicles. Detail recognition of the noise sources, together with frequency bands, would enable the effective selection of the tasks and means minimizing the acoustic effects originating from railway transport.

2. Permissible noise levels – railway transport acoustic annoyance assessment

Noise, in accordance with the encyclopaedic definition, means – “all undesired, unpleasant, annoying or

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harmful mechanical vibrations of the elastic medium, acting over the air on the hearing apparatus and other senses". The definition covers the vibrations of particles, which propagate in the medium as changes in the density and pressure, which form acoustic waves (thickening and weakening the particles of the medium) (Fig. 1).

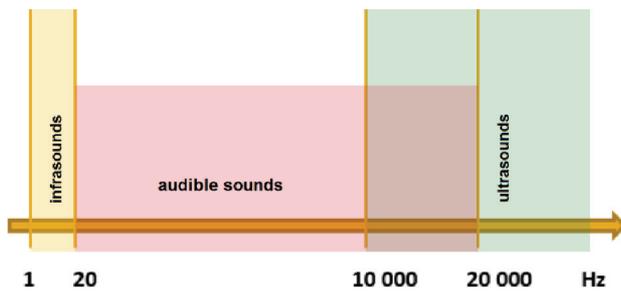


Fig. 1. Audible noise frequency range [5]

Permissible environmental noise levels for noise originating from railway transport are defined in the Minister of Environment Regulation of 14 June 2007 concerning permissible environmental noise levels (consolidated text published in the Journal of Laws 2014, pos. 112) [10]. The regulation [10] introduces a subdivision of the areas protected against noise on the basis of their function and type of buildings. The regulation for different groups of areas defines different permissible noise levels for the day time (16h, from 6am to 10pm) and for the night time (8h, from 10pm to 6am).

The first group of noise protected areas covers health resort areas and areas of hospitals located outside cities. The second group covers the following areas: single-family housing areas, buildings associated with the permanent or temporary presence of children and young people, nursing homes and hospitals within cities. The third group covers the following areas: multi-family housing and collective buildings areas, farm building areas, rest and relaxation areas, as well as housing and service areas.

The last group of areas enables, in the case of cities with over 100 thousand inhabitants, the creation of inner-city areas, i.e. areas defined in local spatial development plans for intensive building within the city with concentrations of service, commerce and administrative objects. Part of an annex to the regulation, which defines permissible noise values for individual groups of areas, is shown in Table 1.

In terms of the character of the changes in the acoustic pressure of acoustic waves as a function of time, noise could be defined as certain (permanent) or not certain (alternating) and intermittent.

In the case of certain noise, the average sound level A (L_{Am}) and equivalent sound level (L_{Aeq}) have to be determined for the time of assessment. Such time is assumed to be the eight most unfavourable hours of the day (6 am–10 pm) or respective thirty minutes during the night (10 pm–6 am).

The equivalent sound level is the permanent sound level, which, acting in the same period of time as the tested sound with an alternating level, carries the same acoustic energy and the same risk of creating harmful

Table 1
Classification of the areas protected against noise and respective permissible environmental noise levels defined by the L_{AeqD} and L_{AeqN} indicators for railway lines

N°	Allocation of the area	Permissible noise levels in dB	
		Roads and railway lines	
		L_{AeqD} day time $t = 16$ h	L_{AeqN} night time $t = 8$ h
1.	a) Areas A – health resort areas, b) Areas of the hospitals located outside cities.	50	45
2.	a) Single-family housing areas, b) Areas associated with the permanent or temporary presence of children and young people, c) Areas of nursing homes, d) Areas of the hospitals within cities.	61	56
3.	a) Multi-family housing and collective building areas, b) Farm building areas, c) Rest and relaxation areas, d) Housing and service areas.	65	56
4.	Inner-city areas in cities with over 100 thousand inhabitants.	68	60

Own elaboration based on [10]

noise. It is calculated utilizing the correction filter A , in the exposure time T_e according to formula (1),

$$L_{Aeq,T_e} = 10 \log \left[\frac{1}{T_e} \int_0^{T_e} \left(\frac{p_a(t)}{p_0} \right)^2 dt \right] \quad (1)$$

where p_0 – is the noise perception threshold for humans of 20 μPa [8].

For the periodic appearance of acoustic phenomena, the sound level is calculated according to formula (2), if the noise level is comparatively permanent in the time lapses $\Delta t_p = 1, \dots, N$, then the formula may be shown in the following form.

$$L_{Aeq} = 10 \lg \left[\frac{1}{T} \sum_{i=1}^N \left(\frac{p_A(\Delta t_i)}{p_o} \right)^2 \Delta t_i \right] \quad (2)$$

During frequency spectrum based assessments, the spectrum is subdivided into octave bands or one-third octave bands with middle frequencies of each band – f_s . This simplifies the comparison of the received frequency spectra, which is performed for the identification of noise sources. The subdivision may be performed thanks to the integration of the continuous spectrum over intervals from lower frequencies (f_d) to upper frequencies (f_g) of the individual one-third octave bands, or thanks to the application of band-pass filters. The width of the octave band is 70.7% of the middle frequency of each octave, while the width of the one-third octave band is 23.1% of the middle frequency of each one-third octave.

$$\begin{cases} f_d = f_s \sqrt[2]{2^{-1}} \\ f_g = f_s \sqrt[2]{2} \end{cases} \quad \begin{cases} f_d = f_s \sqrt[6]{2^{-1}} \\ f_g = f_s \sqrt[6]{2} \end{cases} \quad (3)$$

In reality, direct frequency based analyses are performed frequently on the basis of the iterative filtering of signals by sets of Cauer filters or Butterworth filters with changes in the size of the analysed signal samples and changes in the frequency of sampling. Recommended class 1 measuring equipment usually utilizes Cauer elliptic filters – 6 grade (in accordance with the requirements of the DIN 45651, IEC 1260, ANSI S1-11-1986 standards).

3. The ways to minimize railway noise and their damping effectiveness

The process of generating noise originating from railway transport is a complex problem, as noise level is influenced by many mutually independent factors. The noise emission level depends, among others, on: landform, technical state of the railway superstructure construction and rolling stock, traffic volume and speed [9]. The three main types of noise originating from railway transport are distinguished, depending on the place of origin, into:

- rolling noise – caused by vibrations arising at the rail-wheel contact point,
- engine noise – caused by engine operation (mainly during the start of movement and speeding-up of the vehicles),
- aerodynamic noise – resulting from the disturbances of the elastic medium (air) caused by movement of the vehicle.

Transport noise issues as well as methods minimizing its influence on the environment are widely described in the literature [1, 3, 6, 7, 9]. It is necessary to undertake further activities to minimize noise influence on the environment to maintain the position of railway transport as the most ecological means of transport. The aforementioned activities for reducing railway noise could be divided into three blocks:

- 1) minimizing noise at the place of generation,
- 2) reducing noise along the way of propagation from source to receiver,
- 3) organisational activities [9].

Determining measurable benefits, in the form of noise reduction [dB], in the case of organisational activities is only possible after their application, and they are therefore not covered by this article.

3.1. Minimizing noise at the place of generation

The most effective way to reduce railway noise at the place of generation is to replace old, frequently worn-out rolling stock with new stock. New-generation railway vehicles may be characterised by noise emissions lowered even by 10 dB in comparison to the current rolling stock [9]. Modernizations of the utilized rolling stock are equally effective in reducing noise, as they enable reductions up to even 8 dB (among others, by replacing cast iron braking blocks with composite ones) [6].

Modernization or renovation of the existing railway lines are also ways to reduce noise at the place of generation i.e. in the domain of track superstructure. The effectiveness of such activities is evaluated at the

level of even 10 dB, whereas only rails grinding allows noise to be lowered by about 3 dB. It should be mentioned that the high damping effect of the above-mentioned ways significantly depends on the type of train (their technical state) and speed [9]. In contrast, mounting rail dampers and lubricators, so-called friction changing equipment (applied mainly on curved sections), enables noise reduction by about 2–3 dB [6].

3.2. Reducing noise along the way of propagation from source to receiver

Reducing acoustic effects between the vehicle/railway line and receiver depends mainly on the application of appropriate noise barriers minimising the propagation of those effects.

Up to now, the most commonly applied solution for minimising acoustic effects in railway transport has been noise barriers. Noise barriers, on the basis of the functions they fulfil, are divided into three types: ones which absorb, ones which isolate and ones which disperse sound effects. The efficiency of such contra-noise barriers differs from 8 to 15 dB [1] depending on the distance from the source/receiver, local circumstances and correct design (among others, utilizing appropriate material and adequate height).

Earthwork embankments and cuttings located along railway lines are believed to be the most efficient contra-noise barriers. Their effectiveness enables noise reduction by even 25 dB. However, the construction of such natural acoustic barriers requires relatively wide belts of land, and therefore such counter-measures cannot be utilized in all locations [11].

Green belts along railway lines – belts of land with plants growing to form noise barriers, which are the most ecological and aesthetic way to minimize railway noise – have the lowest effectiveness. The effectiveness of such a solution mostly depends on the amount of leaves, as a contra-noise barrier composed of one metre of plants full of leaves is characterised by the noise reduction effectiveness of between 0.05 and 0.5 dB, while without leaves it's only 0.01 to 0.2 dB [5]. Reaching noise reduction at the level of about 3–5 dB would therefore require a green belt with a width of at least 6–10 m [9].

4. Results of the measurements of noise originating from increased speed rail vehicles

4.1. Localisation of the field measurements

Sound measurements were performed on railway lines 4 and 9 at four measuring point locations:

- 1) railway line number 9, Legionowo – Nowy Dwór Mazowiecki section for the speed of 120–160 km/h:
 - straight section – about km 35+200 – 35+600 (location Janówek),
 - curved section – about km 34+500 – 34+900 (location Janówek);
- 5) railway line number 4, Grodzisk Mazowiecki – Szeligi section for the speed of about 200 km/h:
 - straight section – about km 21+100 – 21+500 (location Szeligi, Dojazdowa str.),
 - curved section – about km 18+900 – 19+300 (location Świnice, Wiejska str.).

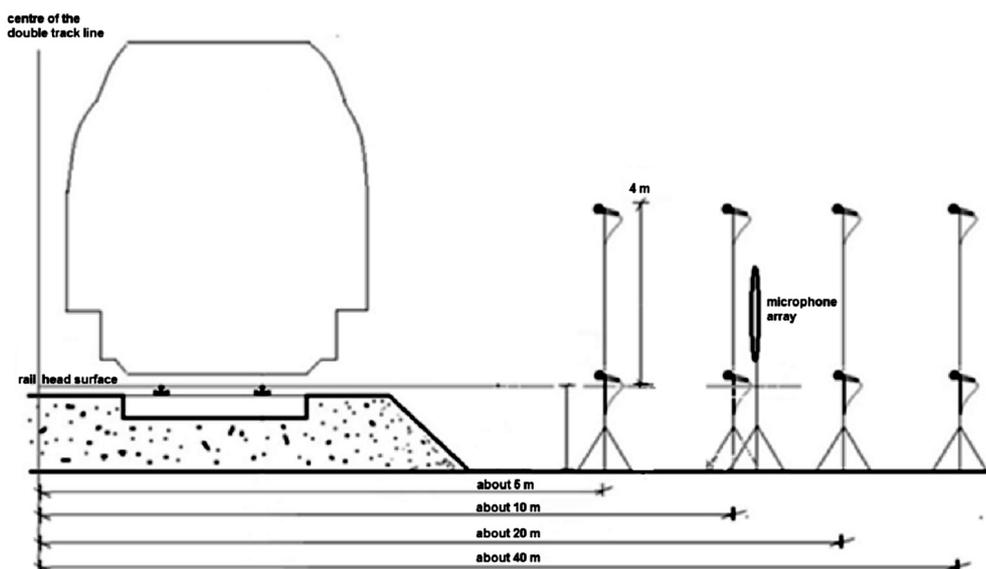


Fig. 2. Intersection of the equipped measurement stand for the field tests [autor's elaboration] [opracowanie autorów]

4.2. Measurement method

Sound level measurement was performed at 4 points using 2 sound level measuring devices (produced by the Svantek company) at each measuring point. Measuring points were located 5 m, 10 m, 20 m and 40 m away from the centre of the track. A detailed outline of the measuring points is presented in Figure 2. Microphones were put at the level of 4 m above the rail head surface and the level of the rail head (about 0.8 m above the ground level). Moreover, a Bionic S-112. 1. microphone array (microphone camera) was utilized for measurements 20 m away from the centre of the track. Measurements were performed on working days (Monday-Friday), 2 days for each of the 4 measuring points during the hours 6 am – 11 pm.

As a result of the performed measurements, the registered timeline history was obtained separately for each train run, with a 1 s step, containing the averaged sound level $L_{Aeq 1s}$ as well as the noise frequency spectrum in the range from 20 Hz to 20 kHz, subdivided into one-third octave bands.

4.3. Weather conditions

In the period during which measurements were performed (the period of the acoustic events), there were no weather conditions that made the tests impossible. Measurements of the weather conditions: wind speed and direction, air pressure, temperature and humidity, were performed with the use of a weather station located outside the range of the gusts created by the running trains at a level of about 2 .

4.4. Pilot test results

Sound level measurements performed with the use of the microphone array showed that, in the case of increased speed rail vehicles, the main source of noise is the rolling noise – the one originating from the wheel-rail vibrations. Measurements were performed during runs of an increased speed rail vehicle (Alstom ED250 series railway vehicle of the ETR610 type) with a speed of 188 km/h. The distribution of acoustic events, in the frequency range from 830 to 885 Hz, during the railway vehicle run is shown in the figure below (Fig. 3).

Analysis has shown that transgressions at the point of contact between the overhead catenary and railway vehicle pantograph start to appear at the frequency spectrum of 190–2340 Hz. However, only one such event was recorded, and therefore it will be closely verified within further test studies as to whether it arose from operational omissions (related to the railway vehicle or railway infrastructure) or whether it was a cyclical event occurring during runs of the

increased speed rail vehicles. This acoustic event is shown in Figure 4.

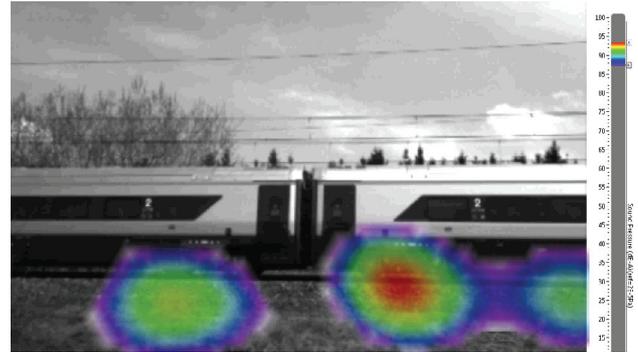


Fig. 3. Sound level distribution in the frequency range 830–885 Hz [autors' elaboration]

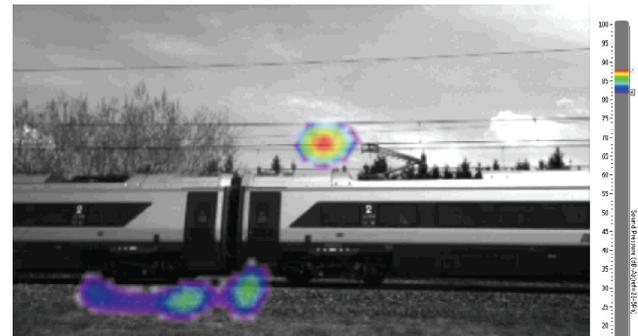


Fig. 4. Sound level distribution in the frequency range 190–2340 Hz [autors' elaboration]

As a result of the measurements performed with the help of the sound level measuring devices, a registered timeline history was obtained separately for each train run, with a 1 s step, containing the equivalent sound level (L_{Aeq}). The distribution of the equivalent sound level measured about 5 m away from the centre of the track for a vehicle moving with the speed of 188 km/h is shown in Fig. 5.

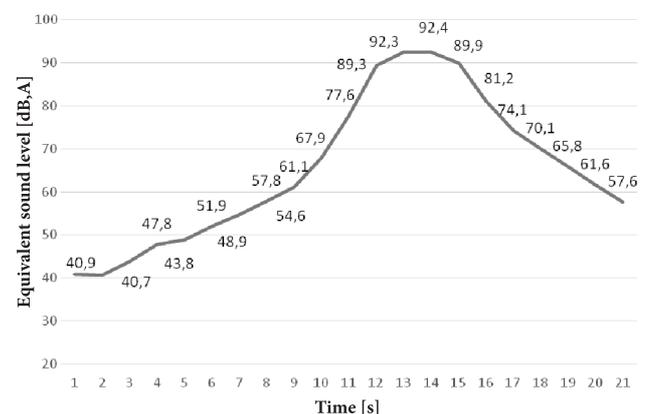


Fig. 5. Equivalent sound level in the time domain, step 1 s, $L_{Aeq 1s}$ [autors' elaboration]

5. Conclusions

Issues regarding the assessment of railway noise emitted during exploitation of increased speed rail vehicles are examined in this work. Identification of the main noise sources deriving from increased speed rail vehicles has taken place. The performed tests have shown that rolling noise, originating from the vibrations at the wheel-rail contact point, is the dominant sound source.

As a result of the performed measurements, a registered timeline history was obtained separately for each train run, with a 1 s step, containing the averaged sound level $L_{Aeq,1s}$ as well as the noise frequency spectrum in the range from 20 Hz to 20 kHz, subdivided into one-third octave band.

Further works on the testing and analysis of acoustic events originating from increased speed rail vehicles would enable the determination of the motives that cause increased noise sources and the creation of an acoustic event model for such vehicles, which could contribute in the future to more efficient minimizing of acoustic effects.

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