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Noise Charge in Rail Transport – EU Regulations Versus Operation of Logistics Systems

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1. Introduction

The different kinds of transport systems, including air, rail and road transport types must reduce the unpleasant and harmful side effects of its operation – noise. Noise impacts can be analysed not only in the surroundings of the transport system, but also, for instance, in terms of impact of noise on the operator (other people, operator) in the cabin of the vehicle, in the compartment where the passengers travel. This paper focuses on the problem of noise in the close vicinity of the transport system; by this we mean people who are often not connected with it, residents of areas close to the operation of transport systems. Many works have been published on this subject, e.g. (Janas 2018, Zagubień 2016, Janas 2019, Jacyna at el. 2018, Szyszlak-Bargłowicz at el. 2013, Profaska, 2012, Chudzikiewicz et al. 2018, Chamier-Gliszczyński 2011a,b). In the next step, the substantive scope of the paper was narrowed down to rail freight transport – the so-called cargo. The issue is entirely new to all, as the EU has introduced a noise-related charge for a freight train running on a specific rail route. The charges are related to people's comfort of living; exceeding the permissible noise level will result in charges and, in special cases, prohibiting overly noisy freight trains from running on certain sections of track, over a certain period of time etc. The noise generated is not always the result of over-exploitation of rolling stock and can cause accelerated degradation of the infrastructure in the close vicinity of the transport system. The implementation of new infrastructure projects will necessitate new solutions for the protection of people and the environment from noise. These are solutions that minimize the acoustic impact of railway lines other than standard noise barriers (e.g. dampers/rail inserts/structural solutions for wagons and locomotives). Ensuring adequate acoustic comfort for rail traffic is now standard practice in the EU. In Poland, PLK S. A., while carrying out works related to upgrade/revitalisation of railway lines, applies special noise protection devices – acoustic screens, which are designed to reflect or absorb acoustic waves in order to maintain the normative noise level for the protected area.

By analogy, hybrid solutions are applied, e.g. vehicles with two power units (internal combustion engine and electric motor), thus making efficient use of available energy possible (Maharjan at el. 2020). This analogy is a hybrid solution where noise protection is in the form of acoustic screens and photovoltaic panels are used that generate electricity, while maintaining the required level of noise protection. In terms of new research, the following are important: optimisation of the use of generated energy (Woźniak et al. 2015), protection of elements of railway infrastructure systems against theft and devastation (thieves and hooligans), constant supervision – monitoring of equipment operation.

This new knowledge will enable the introduction of various sound protection measures appropriate to the severity of the sound source. The developed recommendations will determine their effectiveness and scope of application taking into account the mutual geometric position of the system: sound source – minimizing device – protected area.

All existing solutions meet the provisions of Art. 174 (Journal of Laws of 2013) and the maintenance of the limit values specified in (Journal of Laws 2014) in the areas under acoustic protection, adjacent to railway lines.

2. Analysis of the current situation

Freight trains made up of wagons and locomotives can have different environmental impacts. The noise depends on the type of material transported, speed and the loading of the wagon. In addition, wagons may be leaking and lubricants may leak into the environment.

When analysing the rolling stock, it is possible to carry out the primary division of wagons according to the purpose of the wagon and distinguish between: wagons for transporting cargo and wagons for transporting people.

The second criterion of division may be gross weight of the wagon. A distinction can be made between wagons with one axle, two axles or three axles in the wheelset.

For single-axle wagons, there is no bogie in the suspension, but only an axle-box system with a solebar with a single degree of freedom, enabling vertical movements of the body. The springing element is made up of leaf springs, which are characterized by high internal friction, which is used as a frictional damper damping the body vibrations. These types of wagons have a gross weight limit of about 30 Mg (15 Mg per axle). The lateral and longitudinal movement of the wagon suspension occurs within the existing mechanical play, which limits the maximum speed of the wagon. With the increase of the total weight of the wagon and in order to meet the requirements of increasing the driving speed in the wagons' wheelsets, bogie systems have appeared with two or three running axles, with one or two degrees of springing.

The simplest bogie is the 1XT model with two axles and one degree of springing. The suspension uses leaf springs (two per axle). No additional vibration damping elements were used, but only the internal friction of the spring itself was used for vibration damping. This type of solution has a speed limit of about 100 km/h.

An example of a two-axle single-springing bogie that uses helical springs as a springing element is the 2XT family. 14 sets of spring columns were used in the bogie's suspension (one spring column consists of two springs of different diameters arranged coaxially), with seven springs on each side and a wedge friction damper as a damper. The maximum load capacity of the bogie is 17.5 Mg, and the total rail pressure is 20 Mg.

Three-axle 7TNa bogies, similar in design to 1XT bogies, were used for heavy freight wagons. The suspension uses leaf springs. There were no additional separate damping systems.

Due to the required driving comfort and the ever-increasing need to raise the driving speed of passenger trains, double-axle bogies with double springing are most often used in passenger cars. The most popular family of double-axle bogies for passenger wagons is 25A. In wagons, depending on the maximum permitted speed, the 25AN variety (speed up to 160 km/h) and 25ANa (speed up to 200 km/h) is used. Due to the required driving comfort, a sophisticated springing system is used in the suspension. It comprises the following: springing elements in first degree suspension (between the wheel axle and the bogie), and springing elements in second degree suspension (between the bogie and the wagon body). In some solutions, an elastomeric spring is additionally used between the solebar and the axle-box.

The springing elements are usually sets of springs (two springs each arranged coaxially in different lengths and with different stiffness with counter-torsional coils, which prevents the deflection of one spring from blocking if the other breaks). They are made of 50S2 (55S2) spring steel bars with circular cross-section. They usually have linear stiffness characteristics and minimal hysteresis. A relatively new solution is the use of flexicoil springs. It is made of variable diameter wire, which ensures its progressive stiffness characteristics. In addition, these types of springs have a large outer diameter, which means that they can carry a large amount of lateral loads.

In order to improve the riding comfort and increase the maximum speed (above 200 km/h), air springs are used in the latest wagons. They are characterized by low weight, small size, high durability. Like steel springs, air springs have little hysteresis and require additional vibration damping systems.

Damping is provided by vibration dampers that dissipate the energy of vibrations from both the wagon body and the bogie.

The simplest vibration damper used in the suspension of wagons that use springing elements in the form of helical springs are friction dampers. Here, vibration damping consists in creating a resistance force for the relative movement of two surfaces between which friction occurs. The most commonly used frictional dampers in the railway industry are: cylindrical damper, scissor damper. The structural diagrams are shown in Figures 1 and 2.

The damping characteristics of friction dampers are shown in Figures 3 and 4.

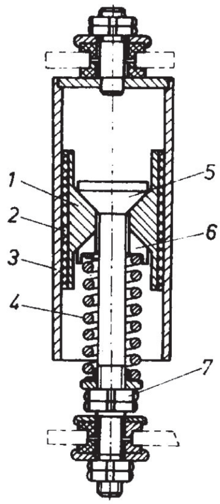

Fig. 1. Cylindrical friction damper diagram: (1 – runner, 2 – pad, 3 – bush, 4 – spring, 5 – head, 6 – wedge pad, 7 – spring tension adjustment nuts)

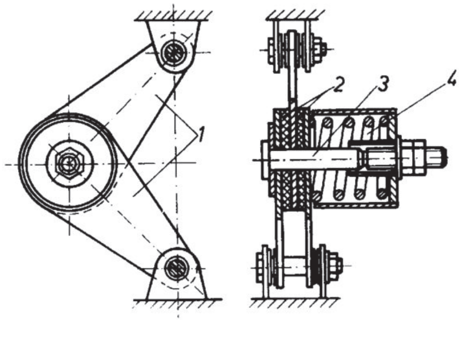

Fig. 2. Scissor friction damper diagram: (1 – arms, 2 – friction discs, 3 – screw, 4 – spring)

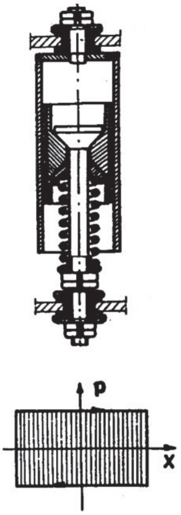

Fig. 3. Damping characteristics of friction damper with constant friction force

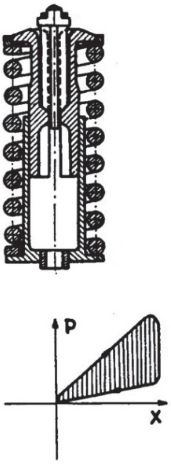

Fig. 4. Damping characteristics of friction damper with progressive friction force

More modern SA hydraulic vibration dampers. These are divided into: single-acting dampers, double-acting dampers (Kosobudzki at el. 2018).

Due to the damping characteristics, the following can be distinguished: linear dampers – the damping increases linearly with the relative speed of the piston and cylinder, non-linear dampers – the damping increases non-linearly with the relative speed of the piston and cylinder.

The engineering diagram of the double-acting hydraulic damper and its damping characteristics are shown in Figures 5 and 6.

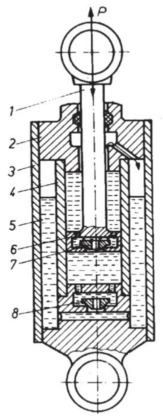

Fig. 5. Engineering diagram of double-acting hydraulic damper: 1 – piston rod, 2 – guide sleeve with seal, 3 – outer cylinder, 4 – inner cylinder, 5 – chamber, 6 – piston, 7 – decompression valve, 8 – compression valve)

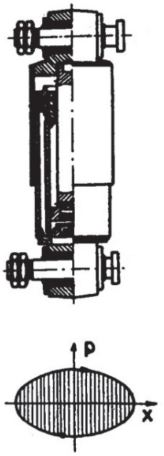

Fig. 6. Linear damping characteristics of hydraulic damper

Hydraulic dampers are used for damping of vertical vibrations (so-called galloping) in the first degree of springing and for damping of vertical, transverse (so-called swaying) and lateral vibrations in the second degree of springing.

Due to their dynamic properties, bogies are classified as supercritical or subcritical. This means that supercritical bogies move at speeds that generate vibrations of frequency exceeding the bogie's own vibrations. An example of this is the 1XT family of bogies. Subcritical bogies move at speeds where the vibrations do not exceed the bogie's own vibrations. An example of this is the 25TN bogie family. It shows an increase in the tendency of swaying (high value of WZ running smoothness index) on tracks with a small width (about 1432 mm) and small rail inclination (1:40).

The solution to improve the WZ index is to replace dry friction sliding elements in the lateral direction in second degree of springing with flexible elastomeric pads. Additionally, to reduce the dynamic loads accompanying the swaying, torsion bars are used in passenger cars, cooperating with horizontal hydraulic dampers mounted between the bogie frame and the car body. The advantages of using dampers for damping the horizontal rotation of the bogie are particularly evident at high speeds (above 160 km/h). The desired shape of the swaying damper hysteresis is rectangular, which corresponds to the characteristics of a friction damper. For swaying dampers, their maximum damping occurs already at very low speeds, in the range of 2-3 mm/s and remains constant also at higher speeds. Another place where lateral loads are damped is the use of spherical layered elastomeric pads applied on spring columns, which not only increase the possibility of relative lateral displacement of the wagon body and bogie frame (longer damping distance), but these pads also act as rubber-metal dampers with high hysteresis and do not affect vertical vibrations in practice. In addition, they isolate vibrations generated by the bogie's wheelset, limiting their transmission to the wagon body (Cunha at el. 2020).

An advantageous effect, due to the progressive increase in stiffness versus deflection and the large hysteresis loop, is brought about by rubber, which is increasingly used as a material for manufacturing damping elements. The damping characteristics of springing elements made of different materials are shown in Figure 7.

Rubber is used to make springing elements in the first degree of springing, e.g. a Chevron spring. They ensure that the bogie's axles are guided in a zero-clearance manner, which significantly reduces impact loads and vibrations transmitted to the wagon body. Modern elastomeric materials are introduced successfully in the automotive industry. It turns out that they have similar properties to rubber elements, but their durability is much greater. In addition, they allow a wide range of changes in their elastic and damping properties through adjustments to the chemical composition.

In order to select the mechanical properties and design the elastic-damping element properly, the entire system in which the element will operate must always be considered. This is why analyses related to the intended operation of the entire assembly are vital. The necessary input data includes information on load spectra, operating temperatures, static loads and dynamic characteristics of the entire system.

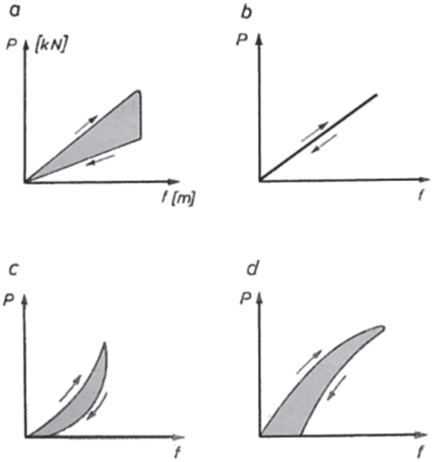

Fig. 7. Damping characteristics: a – leaf spring, b – steel helical spring, c – rubber spring, d – pneumatic spring.

In order to analyse the work of the proposed elastic-damping element in terms of vibration transmission, it is planned to model the dynamic system with the finite element method and multi-body systems as accurately as possible. With the collected information on load profiles it will be possible to determine the routes of vibration transfer through the system and to identify the most important elements affecting this transfer. This will allow to select and focus on developing possible changes in the system that will have the greatest effect.

Elastomeric elements are objects with strongly non-linear characteristics in which it is difficult to separate the purely damping part from the purely elastic part. For this reason, special methods based on the identification of non-linear models should be used for analysis, which may include energy and power balancing methods developed in our department. With appropriate mathematical models and laboratory equipment, it will be possible to design, analyse and optimise, in terms of effectiveness of vibration damping and durability, the proposed solutions for reducing the dynamic effects on the passengers (cargo) transported and the railway infrastructure affected by vibrations caused by train movements.

Cargo in older wagons in particular hit the walls and displace during transport, as shown in the figure below.

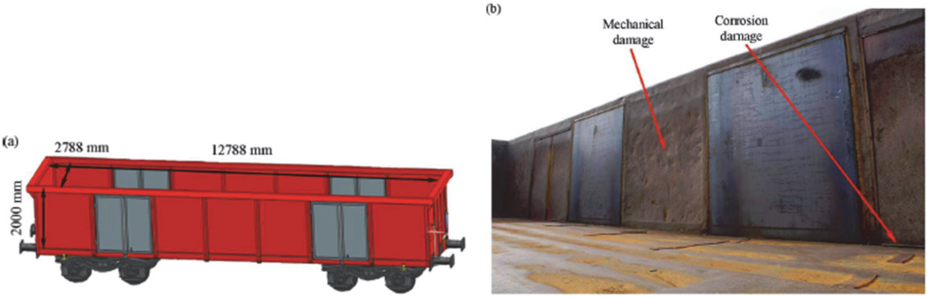

Fig. 8. The EAOS 1415 A3 coal car: a) virtual model, b) damage elements of the box

3. Noise level measurement principles according to [standard]

The noise of freight trains can be measured outside the railway line, as well as inside, for example in passenger cars or at the engineer's position. A draft amendment to the TSI ((EU) No 1304, 2014) was adopted by the EU Member States via the Committee on Railway Interoperability and Safety in 2019. A deadline was set for the mandatory fitting of freight wagons with composite brake blocks.

Work on the revision of the Technical Specification for Interoperability with regard to noise started in early 2016. From the beginning, they have been of great interest due to the potentially high costs of adaptation to new requirements.

The adopted draft assumes selection of special sections of railway lines (so called silent sections), on which freight trains with cast-iron brake blocks will be prohibited. These will be sections with a minimum length of 20 km, on which an average of more than 12 freight trains travelled overnight during the period 2015-2017. The list of silent sections will be published by the European Union Railway Agency 9 months after the specification enters into force. It is to be expected that the main freight lines both in Poland and abroad will be silent sections. In the course of the work, Poland negotiated the so-called special case to allow the continued operation of tyred wheelsets, which constitute a significant part of the Polish freight wagon fleet. These trains will be permitted for domestic service regardless of the status of the line until the end of 2036. They will also be able to enter the Czech Republic and Slovakia without restrictions until the end of 2026. Similar regulations will also apply to other types of wagons, which would be very costly to adapt to new requirements. This will allow railway undertakings operating in Poland to avoid significant costs associated with adaptation to new requirements.

Freight wagons not covered by the exemptions and running on silent sections will have to be fitted with composite brake blocks by 7 December 2024. The process of replacing the blocks can be supported by CEF funding ranging from €250 per wagon in service up to 100 km/h to €600 per wagon in service up to 120 km/h.

Noise level in rail traffic is calculated in octave bands. For rail traffic noise, the A-weighted average sound pressure level is calculated, based on the results obtained for the octave bands, for the daytime, evening and night time as defined in Article 5 of Directive 2002/49/EC, by aggregating data from all frequencies.

$$L_{Aeq,T} = 10 \times \log \sum_{i=1} 10^{\left(L_{Aeq,T,i}+A_i\right)/10}$$

A_i stands for the correction curve A as defined in (PN-EN 61672-2, 2014), is the frequency band index, while T is the time corresponding to day, evening or night time.

The Directive has systematised the classification and descriptors of railway vehicles. In addition, it has been applied to the existing track infrastructure, which is extremely diverse due to the presence of several important elements that determine their acoustic properties and characterise them. Some elements have a large impact on the acoustic properties, while others have a small impact. As a rule, the most important elements affecting noise emissions in rail traffic are: rail head roughness, rail pad stiffness, sleeper, rail interfaces and track curvature radius. Alternatively, the general characteristics of the track can be defined, in which case the rail head roughness and the rate of decay of track vibrations according to (PN-EN ISO 3095, 2005) are two basic parameters determining the acoustic characteristics of the track, plus the radius of curvature of the track. Noise measurement points for calculating equivalent noise sources are shown in the Fig. 9.

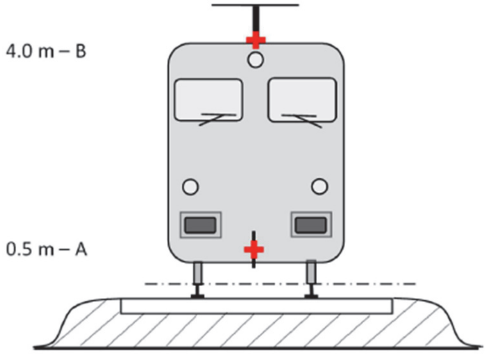

Fig. 9. Location of equivalent noise sources

The physical sources of noise are divided into different categories, depending on the mechanism of noise emission; these are: 1) rolling noise (taking into account not only the vibrations of the sleeper and track as well as vibrations of wheel, but also, if any, the noise emitted by the superstructure of freight rail vehicles); 2) traction noise; 3) aerodynamic noise; 4) impact noise (from switches, crossings and nodes); 5) noise of squeaks; 6) noise caused by the acoustic impact of associated infrastructure facilities, such as bridges and viaducts.

1) Wheel and rail head roughness noise emitted from the three sound propagation routes to the surface of the radiated sound beam (tracks, wheels and superstructure) means rolling noise. It is assumed that the noise source is located at a height of h = 0.5 m (area of the radiated A-beam) reflecting the acoustic impact of track surfaces, including in particular plate tracks (their part responsible for sound propagation) and reflecting the noise impact of the wheels and vehicle superstructure (for freight trains).
2) The heights of the equivalent sources of noise emitted by the train vary from 0.5 m (source A) to 4.0 m (source B) depending on the physical location of the given element. Sound sources such as transmissions and electric motors are often located at the axle height, i.e. 0.5 m (source A). Shutter guards and diffusers can be located at different heights; the exhaust systems of engines of diesel-powered vehicles are often located at roof height, i.e. 4.0 m (source B). Other traction noise sources, such as fans or diesel engine units, may be located at a height of 0.5 m (source A) or 4.0 m (source B). If the exact height of the source location is within the range of model heights, the acoustic energy dissipates in proportion to the nearest heights of the adjacent source. For this reason, the method assumes two source heights, namely 0.5 m (source A) and 4.0 m (source B), while the equivalent sound power associated with each of these sources is divided between the two sources depending on the specific configuration of the source located on a given type of unit.
3) The aerodynamic noise acoustic impact is related to a source located at a height of 0.5 m (modelling of shields and screens, source A) and a source located at a height of 4.0 m (modelling of all components located above the vehicle roof and the trolley, source B). The choice of a source position height of 4.0 m that takes into account the acoustic impact of the current collector is considered to be a simple model, and the adoption of this height requires an in-depth analysis if the main purpose of the model is to determine the correct height of the sound barrier. (UE 2015/996, 2015)
4) The impact noise is related to a sound source located at a height of 0.5 m (source A).
5) The noise from squeaks is related to a sound source located at a height of 0.5 m (source A).
6) The noise emitted by bridges is related to a sound source located at a height of 0.5 m.

4. Transport and logistics system versus the new (EU 2015/996, 2015)

The EU's intention is to create legal and technical solutions that allow for the introduction of charges to carriers for the operation of wagons that fail to meet the standards to a different extent, including with respect to noise. If the carrier refuses to pay the "noise charge" and does not use "silent" rolling stock, his wagons will run on different, usually longer routes compared to silent trains.

Changes in the transport and storage infrastructure may be manifested by an increase in the reloading of goods at intermodal terminals or, in general, at logistics centres.

Until recently, the operation of intermodal terminals was associated with the risk of noise generated during container transhipment. It is relatively easy to protect workers from the negative effects of noise with hearing protectors or anti-vibration gloves. However, the reloading work takes place in the open air and many terminals are located close to residential areas, so it is important to reduce the noise generated during the work.

One of the solutions is to introduce modern silent motors in terminal equipment. The reduction of noise generated during the placement of the spreader on the container, on the other hand, comes from a system for controlling the spreader movement speed.

Reachstackers and cranes (Zajac 2015, 2016) use an optical system mounted under the spreader used to monitor the distance between the spreader and the container. As the spreader hits the container, the spreader lowering speed is reduced (https://intermodalnews.pl).

In the process of transshipment of single cargo, such as containers, the transshipment cannot be carried out by means of tipplers (which is acceptable for granular materials), as is the case with wagons, and transshipment equipment with a spreader or bucket is used instead which is basically "dropped" from a certain height to the level of the container on the railway wagon, hitting its surface.

The capacity of one transshipment machine is currently around 1,800,000 kg per hour; there are usually several of those working on a single transshipment operation. The machines move on rails when unloading containers. Each machine can reach a height of up to 70 m, with a maximum reach of 50 m and a weight of 610,000 kg – 170 of which is the counterweight. The weight of the spreader that is dropped is around 15000 kg (Kwasniowski & Zajac 2016).

The machines are controlled by operators who sit in the cabins at a fairly large height, even about 30 meters above terminal level, using joysticks, aided by image from the CCTV cameras installed on the machine. There are two images: one is the image from the camera mounted on the crane, and the other shows data useful for work. Among other things, the distance between the spreader and the container is indicated – i.e. the place of unloading. The meters remaining to the container are calculated by the operator, however.

Combining these two opposite trends in the context of noise reduction at transshipment terminals, i.e.: noise reduction by reducing the transshipment speed versus increasing the transshipment speed in the context of increasing the efficiency of transport systems (Zajac & Kwasniowski 2017, Woźniak et al. 2015).

5. Conclusions

1. It is reasonable and understandable to set a permissible noise level for freight trains in the EU – such regulations have already been introduced for air pressure control systems in car wheels, for example. At present, the noise level has been set for freight trains. In addition, there is discussion among EU experts on the introduction of a minimum value for the air resistance coefficient – to charge for vehicles that have a c_x value that is too high, which translates into its energy consumption.
2. The setting of an acceptable noise level for means of transport protects against the negative effects of noise on the human body. The formulation of guidelines for the determination of permissible noise levels is justifiable – not only in the human context but also in the environmental context.
3. A charge for exceeding the permissible noise level in rail transport may result in a transfer of the cargo stream to other modes of transport but it is likely to generate additional transshipments at terminals from “noisy” to “quiet” wagons, in logistic centres, which may reduce noise on the railway line but increase the noise caused by transshipments at unauthorised times, resulting in exceeding the permissible noise levels in the silence zones neighbouring with logistic centres. This increase in noise is expected to be significant.

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Abstract

The paper discusses the way of determining the noise level in railway traffic according to new EU recommendations, the introduction of which will result in new charges to be borne by the carriers who, during the provision of transport and handling services, use wagons of the old generation – i.e. such wagons that generate noise above the permitted level on a given section of railway road, determined on the basis of EU regulations. The analysis of technical condition of wagons used in transport in Poland was conducted. The method of determining the noise level in terms of exceedances and charges was discussed. The issue of an optional increase in the reloading of cargo units at railway terminals to transport cargo in silent wagons on designated silent sections of routes was raised – this may affect the development and operation of logistics centers.

Keywords:
charges, noise, wagon, train, noise measurement, noise standard

Opłata za hałas w transporcie kolejowym – przepisy UE, a działanie systemów logistycznych

Streszczenie

W artykule omówiono sposób określania poziomu hałasu w ruchu kolejowym według nowych rekomendacji UE, których wprowadzenie będzie skutkować nowymi opłatami ponoszonymi przez przewoźników, którzy podczas świadczenia usług transportowo-przeładunkowych korzystają z wagonów starej generacji – tzn. takich wagonów, które generują hałas powyżej dopuszczalnego na danym odcinku drogi kolejowej, ustalonego na podstawie przepisów UE. Przeprowadzano analizę stanu technicznego wagonów stosowanych w przewozach w Polsce. Omówiono sposób określania poziomu hałasu pod kątem określenia przekroczeń i opłat. Poruszono zagadnienie opcjonalnego zwiększenia przeładunków jednostek ładunkowych na terminalach kolejowych aby na wyznaczonych cichych odcinkach tras ładunki transportować cichymi wagonami – co może wpłynąć na rozwój i działanie centrów logistycznych.

Słowa kluczowe:
opłaty, hałas, wagon, pociąg, pomiar hałasu, norma hałasu