# ACOUSTIC AND SOUND INSULATION IN RAIL SYSTEMS



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## Abstract

This paper discusses about the acoustic and sound insulation methods and applications in railway systems. The sources of generated noises from the railway systems are introduced. Then, the relevant methods for reducing the noise and vibration from such systems are discussed. Moreover, new strategies for railway system sound insulation will be discussed. This can provide a comprehensive guide for engineers to deal with noise, vibration and acoustic design of trains, railways and related structures.

**Keywords:** Acoustic, Noise, Sound, Insulations, Railway, Trian, Rails, Design

## 1. Introduction

Railways are environment-friendly and sustainable development solution for transportation. However, noise and vibration remain a major reason for objections to new lines or network expansions. Noise is an annoying phenomenon, contaminating the environment and adversely affecting the health of people exposed to high ambient noise levels. The discussion about railway noise has become very important as railway transport increases and plays a more key role in greening transportation.

Railways will never be silent but, it is nevertheless important to reduce their noise and vibration as much as possible while not adding unnecessary cost or complication to their construction and operation. To achieve this, it is essential to understand the sources of noise and vibration and the parameters that can influence them to propose cost-effective mitigation measures. Theoretical models are an important part of this process. Such models should be of sufficient detail to cover the most relevant parameters in a reliable way, but not over-complicated in order not to lose insight. Railways are undergoing a renaissance in many countries as they become seen as a more sustainable and environmentally-friendly means of transport than road or air. As new lines are planned and opened in many countries, and as line speeds and traffic densities are increased, the resulting noise and vibration take on a growing importance. Residents use noise and vibration as a means of objecting to railway developments and consequently expensive mitigation measures must be included in modern designs. Railways will never be silent; to move enormous quantities of passengers or freight at high speeds will inevitably involve the generation of significant noise and vibration through both mechanical vibration and aerodynamic noise. Nevertheless, it is clearly important to reduce its impact as much as possible while not adding unnecessary cost or complication to the construction and operation of the railways. To achieve this, it is essential to understand the sources of noise and vibration and the parameters that can influence them, to propose cost-effective mitigation measures. Theoretical models have been developed for many railway noise phenomena [1].

In general, three various sources of railway noise are identified: engine noise, rolling noise, and aerodynamic noise. Railway noise is largely a problem of freight trains and trains containing older wagons or engines and is a particularly severe problem during the night. The dominant source of noise from operational railways in most situations is rolling noise due to the rolling of the wheel along the rail. The surface roughness (unevenness) of the wheel and rail induces relative vibration of the wheel and rail, the vibration amplitude of each component depending on their dynamic properties. The resultant vibration then radiates noise. Modelling of rolling noise began in the 1970s with Remington's work [2,3].

Analytical models were used for the wheel and rail impedances and for radiation efficiencies. His work took account of many features that are still considered as important: relative displacement excitation by the roughness, the contact filter effect, track decay rates, etc. Subsequently this basic model was developed and extended to include other features that were found to be significant [4-9], and this was implemented in the TWINS (Track-Wheel Interaction Noise Software) package on behalf of the European railways and validated using extensive field tests [10].

Unlike the wheel, the rail is effectively an infinite waveguide which sustains propagating waves rather than resonances. The decay rate of these waves with distance along the rail determines the length of rail that vibrates with each wheel and thereby controls the radiated power. The vertical dynamics of the rail can be adequately modelled using an analytical model of a beam on a two-layer elastic support; rail pads and ballast are represented by elastic layers while the sleepers are represented by their mass or by a transverse beam.

## 2. Active and Passive Noise Control Methods for Railway System Applications

There is a significant difference between managing the acoustic design of a completely new vehicle (passive noise control) and making improvements to an existing one (active noise control). The latter either by carrying out modifications to newly built wagons, or if an existing one is to be modified to meet specification requirements or cope with passenger complaints. In every case, the operating conditions must be specified, e.g. on straight track or in tight curves, at which speed, high speed or standstill. Prevalent weather conditions at operators' locations must be considered, especially in case of HVAC operating states or heat blowers during mild winters. But also, disturbances to passengers themselves must be respected, since open saloon compartments are the most popular for short and long-distance journeys. So, people in loud conversation, using mobile phones or any kind of consumer electronic device must all be considered.

For new vehicles in the early phases of construction, the acoustic design must be performed digitally. Scaled vehicle models for investigating interior acoustic behavior are expensive and unpractical. Acoustic properties of single components or units must be determined to validate calculations and improve the accuracy of results. Passenger comfort in rail vehicles, both mainline and suburban, plus trams, always depends mainly on air-conditioning, vibrations and noise. Offering sufficient levels of comfort is a complicated procedure. First different noise sources and the kinds of acoustic disturbance must be established. If the noise sources are at the lowest acceptable level, then the acoustic design must develop solutions to improve the situation to meet requested noise values. Material must be selected, and geometries defined. Very often, demands for thermal insulation, fire safety and space gain influence the design process. Exterior noise sources Mainly from rolling noise, very high noise levels are emitted from the running gear, the track and sleepers rolling noise source is speed dependent [1], [2].

As the standard of living rises and the quality of life improves and as, at the same time, the territories are becoming more and more urbanized and the need for transport increases, the effect of noise made by transport is increasingly becoming a critical issue, especially in densely populated areas. Even though most of population is affected by the road transport noise (~ 90 % of the population is affected by the noise levels of > 65 dBA), the railway noise also has a negative effect (1.7 % of the population is affected by the noise levels > 65 dBA) [1]. This is especially important in densely populated zones crossed by railways. For instance, the study conducted at Paneriai railway station (Lithuania) reveals excessive noise limits (> ~ 8 dBA) [2]. In such places, appropriate measures must be taken to protect the surrounding areas from the impact of noise caused by railway traffic. The problem is that proper noise mitigation measures are not always chosen based on specific local conditions.

Railway-related noise is most often caused by the wheel–rail interaction, which may be divided into three groups [3]: - Rolling noise. The roughness of the wheel and rail surface is the basis for rolling noise occurring on straight tracks. This is the reason why relative vertical vibration occurs. Rolling noise is basically a linear process. - Impact noise. This is a more severe case of rolling noise. However, it is not a linear process. The impact noise occurs due to cracks (defects) on the surface of the wheel or rail. - Squeal noise. This kind of noise occurs in small-radius curves. It is usually due to lateral wheel to rail interaction.

Townes et al. [4] provide a slightly different categorization of the noise due to wheel–rail interaction: - Noise at tangent track - Noise at curve - Impact noise occurring because of the joints, special trackwork, etc. Rolling noise with a typical frequency range between 100 and 5,000 Hz occurs more often compared to other types of noise, such as the squeal or impact noise [5]. A (relative) vertical displacement between the rail and the wheel is produced by the wheel–rail roughness [1, 6]. High-frequency vertical vibrations occur at the contact area and are transferred to both structures.

Tunnels are exceptional cases because they usually lack absorbent surfaces and so high outside noise levels appear. Consequently, geometrical damping of the noise source in free-field no longer exists and the noise level on the roof of a car is equal to that in the middle. For fire safety reasons, new lines are designed with single track tunnels. From a noise perspective, here the situation is even worse than for double track tunnels. An additional noise source may occur in tight curves, mainly for trams: wheel squeal [3].

There is a lot of noise producing equipment in modern railway vehicles. It is important to distinguish between airborne and structure-borne noise. The latter is influenced by the excitation location, the method of fixation and force transmission. Air conditioning has many noise sources, e.g. the compressor, cooling stream, air flow and fan. Air distribution in shallow ducts and small nozzles may create noise too. Vehicles with propulsion systems have many additional noise sources: drive engines, e.g. electric or diesel engines, gearboxes or rectifier noise including noise from their cooling systems. Operating conditions also play a key role in generating noise. For drive systems, acceleration and decelerating procedures at low speed play a key role. This equipment very often radiates noise with harmonic components, which is extremely annoying [6].

Rolling noise is generally higher from poorly maintained rail vehicles, and from trains running on poorly maintained infrastructure. Aerodynamic noise is particularly relevant for high speed lines where, in most cases, noise limiting measures like noise barriers are implemented; noise barriers reduce the impact of rolling noise but are usually too low to have any effect on noise originating at the pantograph. Engine noise is most relevant at lower speed, rolling noise above 30 km/h and aerodynamic noise dominates above 200 km/h. The most important noise source is rolling noise, which affects all kinds of train.

To reduce railway noise pollution, passive measures at the place of disturbance can be distinguished from active measures at the noise source. The most important passive methods used to reduce the impact of railway noise on the environment are noise protection walls and insulating windows, and for the most part action plans and investments of the Member States concentrate on these methods. However, they are only locally effective, requiring huge investments to protect wider parts of railway networks. In contrast, source-driven measures lower noise across the whole railway system if they are widely introduced. As an example, the problem of noisy rail freight cars can be reduced by the replacement of cast iron brake blocks by composite brake blocks. This is currently being investigated by the railway industry and would affect about 370,000 old freight wagons. Also, wheel absorbers, aerodynamic design of pantographs and noise insulation of traction equipment (e.g., locomotive engines) are measures to reduce noise at source.

According to the current Technical Standard for Interoperability (TSI Noise), rolling stock which was introduced since the year 2000 (including engines and passenger coaches or passenger power cars) are required to lower noise emissions by about 10 dB(A) compared to the equipment of the 1960s and 1970s. In the authors' opinion, noise should ideally be reduced at the source because these measures have a network-wide effect. Where track infrastructure causes increased noise levels (e.g., structure-radiated noise from viaducts or curve squeal in narrow radius curves), or where the local environment is particularly sensitive to noise (e.g., areas of natural beauty or urban environments with residences very close to the railway line) then additional trackside noise mitigation measures may be necessary. Such measures include friction modifiers, rail dampers, floating (or isolated) slab tracks and of course noise bunds and barriers in various heights. Vehicles and track should all be maintained to eliminate unnecessary sources of noise, e.g., corrugation.

As rail freight wagons commonly travel across wider international distances, it is essential to harmonies noise legislation policies across Europe. As a result, the authors recommend focusing on the following actions:

- Retrofitting the existing freight wagon fleet with low noise braking systems especially by replacing the cast iron by composite brake blocks as the most important and effective first step of source related noise reduction measures.
- Establishing funding schemes to cover the retrofitting and additional operating costs of the new noise reduction technologies to avoid a reduction of the rail sector's competitiveness; a substantial part of costs should be covered by the Member States, since quieter trains will reduce the need for, and therefore the cost of, infrastructure noise mitigation measures, introducing rail track charging systems which differentiate the train charges according to the noise category of a train. The noise classification of a train should be determined by the wagon with the highest noise emission level.
- Making activities concerning NDTAC or noise limit regulation depending on the same actions in road transport to avoid losses of competitiveness for the rail sector.
- Making noise limits by TSI Noise ([TSI Noise 2011] also compulsory for existing rolling stock 10 or 12 years after introduction of funding schemes and noise limits for new rolling stock.
- Adjusting limits of TSI Noise in a phased process for a medium and long-run future to foster the development of new noise reduction technologies. Monitoring and maintenance of noise development due to abrasion to assure low noise levels also during operation over extended periods.

As it is already indicated, main source of railway noise is rolling noise coming from rail freight wagons. Of minor importance is engine noise (at lower speeds) and aerodynamic noise (high speed trains). Locally also squeal noise can be important. Rolling stock which is introduced from the year 2000 on is about 10 dB(A) less noisy then rolling stock from the 1960s and 1970s. Against each source of noise an enormous number of measures has been developed in the last years. Rolling noise and wheel noise can be reduced by composite brake blocks (freight wagons), resilient wheels or wheel dampers. Rail noise can be reduced by rail dampers, resilient track pads and combinations with noise barriers of different heights. Track side or vehicle side lubrication systems can avoid squeal noise and are well introduced in tram way systems. The most efficient measure to achieve network wide noise reduction is the retrofitting of freight cars with composite brake blocks.

## 3. New methods for acoustic and sound insulation in railway systems

Development and Practical Application of a Sound Absorbing Panel Using Microperforated Aluminum for Shinkansen Tunnel Entrance Hoods has presented the new sound absorbing technology developed using microperforated panels, which was adopted for use in a Shinkansen system for the first time. By taking advantage of the features of this noise control technology, such as acoustic performance and strength properties, we will develop more applications in traffic infrastructure including Shinkansen systems. We will build on the findings of the above development project and consider developing products that can accommodate environments which require even greater strength. We hope that this work serves environmental preservation purposes. In developing the product, we received many useful pieces of advice from individuals from West Japan Railway Company and other organizations who were concerned with the project. We express our sincere thanks to these individuals.

Sources of railway noise are Areo-dynamic, Propulsion system, Rolling wheel/rail system. Speed relation for the three noise sources: the rolling and aerod7ynamic noises are increasing with respect to the train speed. In fact, the dominant source of noise in conventional speeds is the rolling noise which is induced by the roughness of wheel and rail running surfaces. In high speed the emitted noise from the wheel is more than the noise of rail. The highest level of emitted noise from the wheel and rail shall be happened around 1000 Hz. As in this frequency, the maximum radiation ratio is occurring. One solution is to use Rail pad which defines coupling between rail and sleeper to reduce the emitted noise from the structure. They are inserted under rail to protect sleepers. They have a considerable influence on the noise. However, as the stiffness of rail pads is changing with respect to frequency, therefore its damping capacity is also changing. Various modes of vibration can be seen with respect to the frequency for the rail.

In general, low roughness, wheel structure damping, track structure damping, local shielding, insulation and barriers can be considered as the solutions for the noise reduction in railway system. In fact, the rail roughness, the more braking noise will occur. One solution is to use rail grinding to reduce the rail roughness. However, the roughness will return after some years again and it increases the radiated noise from the rails again. Also, the shape of wheel is very important. Normally an optimum shape of train wheel shall be in the form of straight and thick web, but it conflicts with other requirements. Also, smaller wheels can be dramatically quieter. Therefore, it is very difficult to optimize the geometry of train wheels. Another solution is to use wheel damping. Although it can be happened that good result are achieved in the lab but in the field can be disappointing. Rail dampers can another alternative yet. Various types of rail dampers have developed in different countries. In fact, Rail pad defines coupling between rail and sleeper. As the high stiffness pad represents the strong coupling and good energy transfer from low damped rail to high damped sleepers. Some of them have tuned mass-spring systems. Rubber can be also used to give effect over broad frequency range.

Skirts or vehicle mounted barriers are Only effective in combination with track mounted barriers. Some Mini barriers for sheilding of rail radiation and preventing from multiple reflections can be used as well.

Currogation of wheels has the highest effect on the noise radiation level. After that, pad stiffness, currogation of rail, track width, distance of sleepers, type of rail and stiffness of balast have effect on the noise emission from the railway system.

One other methods is Non-standard rail construction (slab track). It is preferred in construction for high speed lines in Germany and Netherlands as it is a stable system, even at soft soil, minimal maintenance, but with high initial costs.

Types of track construction is another critical issue which should be considered. Elasticity in track system is essential to prevent cracks in rail. Conventional ballast track, Flexible mounted sleepers in concrete slab, Rigid mounted sleeper in concrete slab and Rail directly mounted in slab are the available tools at this regard. However, Slab tracks are noisier then conventional ballast tracks. It is mainly due to Less tight rail to sleeper connection, less damping and No acoustic absorption from ballast. Noise difference ballast or slab track is a function of frequency. It says the slab track Effect centered around 800 Hz of rail contribution.

One suggestion for Noise improved design is Higher rail damping, Tighter connection with sleeper, and Damped fixation of sleeper in slab. Cork-rubber with optimal dynamic properties is another solution.

Curve squeal or Curving behavior is another issue to be considered. In ideal curving, the wheel-set would be aligned radially. A stiff bogie frame overcame stability problems at high speed, but curving is not ideal. For Reducing of squeal noise, lubrication, steerable wheelsets, wheel damping and asymmetrical rail profile grinding can be helpful.

Creep force is also important. Creepage induces a friction force, the lateral creep force. At high creepages, the creep curve falls as the dynamical coefficient of friction value is less than static value. The falling creep force is equivalent to negative damping. If this exceeds the damping of the wheel, large amplitude self-excited vibration occurs.

Finally, it can be said that one need to identify the dominant source of noise and tackle it at first. When more than one source contributes they, all need reducing. Wheel and rail are important in rolling noise. Only wheel is squeal. If one reduced, another may get worse. Very small wheels can increase track noise. Control at source is most effective. Controlling roughness affect all sources. Wayside noise barriers are less effective than source treatments. Ring damper can effective for squeal but not give enough damping for rolling noise.

There also some other new methods for the reduction of emitted noise from the rail way systems. Usage of novel meta-structures for tunnels, bridges and rails are considered. Structure with negative Poisson ratio can perform well under pressure and bending loads. Passive design optimization methods have been widely investigated by Ranjbar et al. for noise reduction applications [8-23]. They have shown than designing a quieter structure is more logical than try to make the structure after design and production. Usage of auxetic structures and materials like foam is another option for noise reduction in various parts of train structure. The vibration energy can also be harvested to produce electrical energy instead of letting it to be converted to noise. Geometry optimization of the train and locomotive is another new and emerging field for noise reduction and better structural acoustics properties.

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