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Review of railway rolling noise and ground vibration and track-related mitigation measures-recent developments

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Abstract

Railway Noise and vibration pollution affect millions of people globally, especially those who live close to or near the railway line. Although railway transportation mode is known as environmentally friendly technology, its contribution to noise pollution is no less a degree. Many experimental and observational studies show an adverse effect of noise and vibration on human well-being. The primary purpose of this paper is to overview the source of railway noise caused by primary sources, mainly rolling noise and ground vibration, and the development of recent railway noise mitigation measures in consideration from a track-related perspective.

Keywords: Ground vibration, Rail pads, Railway rolling noise, Track-related noise mitigations, Wheel/rail interaction

Demiryolu yuvarlanma yüzeyi gürültüsü ve zemin titreşimi ve hat ilişkili azaltma önlemleri-güncel gelişmeler

Özet

Demiryolu gürültü ve titreşim kirliliği, özellikle demiryolu hattına yakın veya yakınında yaşayanlar olmak üzere, dünya çapında milyonlarca insanı etkilemektedir. Demiryolu ulaşım modu çevre dostu bir teknoloji olarak bilinse de gürültü kirliliğine katkısı azımsanmayacak kadar az değildir. Birçok deneysel ve gözlemsel çalışma, gürültü ve titreşimin insan sağlığı üzerindeki olumsuz etkisini göstermektedir. Bu makalenin birincil amacı, başta yuvarlanma yüzeyi gürültüsü ve zemin titreşimi olmak üzere birincil kaynaklardan kaynaklanan demiryolu gürültüsünün kaynağını ve demiryolu hattı bakış açısıyla güncel demiryolu gürültüsü azaltma önlemlerinin geliştirilmesini gözden geçirmektir.

Anahtar Kelimeler: Zemin titreşimi, Ray yastı, Demiryolu yuvarlanma yüzeyi gürültüsü, Hat ilişkili gürültü azaltımı, Teker/ray etkileşimi

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1. Introduction

Noise, as an environmental pollution issue, is increasing all around the world with urbanization and industrial development. According to the Environmental Noise Directive (END) of the European Union (EU), about 100 million people in Europe are influenced by traffic noise and resulting in a loss of 1.6 million years of healthy life [1]. Many experimental and observational studies show the terrible effect of regular noise exposure on daily human activities such as education, working, sleeping, etc. [2–6]. Based on old studies, noise and annoyance stemming from railway transportation are relatively less than other modes [7–10], but the increasing amount of laid out railway networks throughout the world jeopardizes public health [11–17]. Especially in passenger transportation, reducing noise is essential for achieving a higher level of comfort[18]. Noise reduction efforts at railways mainly concentrated on freight traffic because of the necessities such as long rolling stocks, braking systems, and night running time-limited by operable legislations [19].

Before the actions are taken about noise reduction, it may be efficient to determine where the noise comes from in the railway. Noise and vibration sources in railways can be classified as mainly [20]:

- Rolling noise; it is originating from rail and wheel contact
- Ground vibration and noise; noise and vibration transmitted to the ground
- Aerodynamic noise; comes from the flow of air that passed all around the train
- Curve squeal; is caused at railroad bend
- Bridge noise; happens when the railway vehicles cross the bridge
- Traction equipment, horn, road crossing, and other noise

This paper discussed the identification and modeling of rolling noise and ground vibration in addition with track -related mitigation measurements in consideration of state-of-art.

2. Rolling noise and ground vibration

The rolling noise and ground vibration are accepted as primary sources of noise for conventional/high-speed passenger and freight railway operations produced from the wheel-rail interaction process. Both rail and wheel contact surfaces have a considerable amount of roughness, and this culminates in vibration. The transmitted vibration induces radiation of noise. As a matter of course, roughness and design approach, and velocity-dependence are the other factors affecting the rolling noise mechanism [21].

The most widely known analytical model was first developed about rolling noise phenomena by Remington with the presentation of the contact surface and its filtering effect. Besides these, sound/vibration generation and propagation, evaluations of wheel and rail impedance at vertical-horizontal direction were determined in one-third octave band frequency domain even though the limitations of the model [22–24]. This model was enhanced by Thompson and introduced with a series of papers that adequately explain the rolling noise mechanism[25–30].

As a result of the efforts made by the European Rail Research Institute (ERRI) and the scientists, as mentioned above, a software package program was developed, which is called TWINS ("Track–Wheel Interaction Noise Software"). As can be seen in Figure 1 [31], TWINS is based on rail/wheel roughness and interaction, the response of structures, including sleepers, and resulting from noise and its propagation. According to this developed model, an assumption is about roughness that affects only a single point of the rolling surface and does not contact patch size and shape. The roughness values are taken in a wavelength with frequency formula when train speed is V. Except for two extreme cases (so small and large amplitudes), linearity between the radiation of noise and roughness can be referred to. Some parameters such as corrugation of rail, polygonization of the wheel, and measurement methods of both of them were taken into consideration [20].

The following equation (Equation 1.) is used to show the relationship and proportionality between the rolling noise and the train's speed. When doubling up, the speed causes the increase in A-weighted sound level by about 8-10 dB [32].

$$L_p = L_{p0} + N.\log_{10}\left(\frac{V}{V_0}\right) \quad (1)$$

L_{p0}= the sound level at a reference speed V_0
N = an exponent derived from measurement data with linear regression

Experimental validations were achieved in [31,33] by considering different types of rolling stock (passenger and freight), rail, rail pad, sleeper, brake application, and wheel structures with the configuration of speeds, but standard ballasted construction with TWINS. Also, predicted and measured noise levels quietly close to each other in overall noise by about ±2 dB.

Two main ways exist for the measurement of roughness that is classified as direct and indirect methods. In the direct method, the wheel and rail are examined separately with scanning instruments. In the indirect method, the roughness of wheel and rail values is considered together with onboard devices when the train runs [34]. Another direct measurement method, based on pass-by analysis, offers an advantage in driving track decay rates and transfer functions with the combined wheel/track roughness [35].

The wheel's contribution to all radiated sound from the rolling noise is accepted at high frequencies; rail contributes substantially for all frequency regions. Variation of frequency interval for wheel-related noise generally in 1-2 kHz is associated with design parameters such as geometry, web shape, etc. [32,36].

In addition, the studies show that the existence and propagation mechanism of ground vibration is closely related to not only the speed of the train and wheel/rail interactions and also the complex relations of the track, vehicle, and soil used in railways infrastructures must be taken into considerations[37–40]. For instance, a theoretical study investigated ground vibration generated by vertical track irregularities with three subsystems; vehicle, track, and layered ground. The vertical irregularities and axle loads were used as inputs. Single axle model passenger coach on three different ballasted tracks (light, heavy, and slab) was run at 25, 60, and 83 m/s speeds. From this model, the wheel-rail dynamic force and the maximum displacement along the track center-line on the ground surface were calculated for a single-axle vehicle model and for two different ballasted tracks. The heavy track makes a slight reduction compared to the light one in the upper-frequency range. The slab track is more efficient than others in the low-frequency range[41].

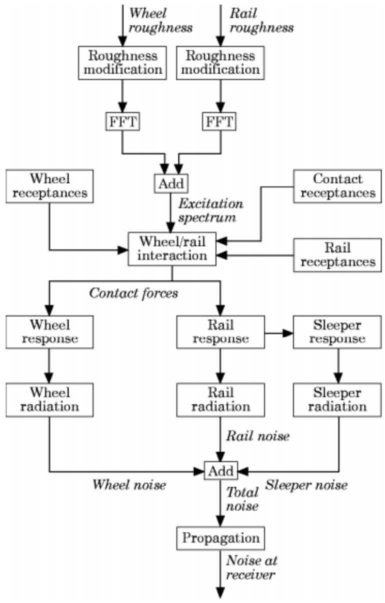

Figure 1. Schematical diagram of TWINS model [32]

The more current investigation was conducted about ground vibrations with consideration of the effect of vehicles, track, and soil types. Researchers reviewed and discussed the vehicle axle-load characteristics based on constant, randomly varying, and multibody approaches. The multibody system offers more accuracy when compared with the light of numerical and experimental investigations. In the same perspective, the results of track defects were summarized[42].

Moreover, another comprehensive numerical study shows the effect of railway vehicles types on the ground vibration levels. Four vehicle models (3 are passenger express and 1 of them is freight train) that were configurated with different carriages, bogie types, and car numbers on flexible tracks were engaged with constant speed for simulation of wave propagation. Wheel receptance, track deflection, and free field ground vibration mechanisms were explained by the number of figures and tables according to the multibody vehicle system model (MBS), MBS model with perfect track and moving axle load model. The track modeling is based on a three-layer model (rail – rail pad – sleeper – ballast – foundation) that explains the vertical track behavior. The dynamic forces were calculated by Hertzian theory, which stems from wheel/rail contact area, and the finite/infinite element model was used for the soil [43].

Also, another well-established and remarkable study was conducted with the data across 7 European countries, including over 1500 ground vibration records at 17 high-speed rail sites. The influence of train speed (72 to 314 km/h) on the ground vibration by consideration of frequency spectrum. In order to determine vibration levels, the VdB metric was chosen and calculated with a logarithmic scale. Also, Peak Per velocity (PPV) and a weighted time-averaged signal (KBf (t)) [44] were used for the metric purpose. The results show that VdB is more suitable than other metrics. All train types almost had the same ground vibration levels when close to the track but differed with distance, but this discrepancy caused making difficulties in the vibration levels prediction stage with large offset values. Increasing train speeds would not affect the increase of vibration levels. Researchers emphasized that soil material properties were the most effective factor in ground vibration levels [45].

In this sense, the next section includes mitigation techniques for rolling noise and ground vibration that addresses track-related measurements about the last decade.

3. Mitigation techniques for rolling noise and vibration in railways

The railway industry has strived to overcome noise reduction problems at the mainline and urban region lines for a long time. Although some important remarkable steps were taken, still noise-related issues about freight stocks and high-speed trains have not been solved yet [46].

From the scientific point of view, the effective ways of noise reduction usually are considered on a preferential basis at the source of noise and active mitigation measurements by new designing efforts. If it is not passive, measurements must be taken [47].

As it is understood from the literature[19,47,48], we can classify and examine the abatement methods at different subtitles as active/passive manners or track-related/vehicle-related. In this paper, the track-related noise measures were discussed in terms of active and passive mitigation techniques.

3.1. Rail dampers and rail pads

In simple terms, a rail damper is an elastomeric fixed element that can be attached to both sides of the rail by clips, glue, or bolts [49]. The purpose of using rail dampers is to increase the railways' capacity to dampen noise stemming from wheel/rail contact [50]. A broad review was prepared on the use of these plastic materials for damping purposes in railway track systems [51].

Rail dampers can be mounted on the rail both in discrete and continuous forms. The discrete type is fixed on the rail with an equal distance between two sleepers' bays or the fastening instruments. The continuous rail damper is mounted along with the rail, but its utilization is very rare. The working principle of the rail damper is based on the rubber material's damping capacity, which reduces the rail vibration by energy dissipation in damper steel (embedded) elements and elastomer. The vibration energy damping ability of rail dampers is defined by the stiffness and damping coefficients of the rubber. The absorbing capacity can also be defined by operating frequency, and the effective damper's range varies between 500 and 2000 Hz [52].

Another performance benchmark for rail dampers is track decay rate which is defined as decreasing rate of vibrations along the longitudinal scale of rail with the unit as dB/m. Comparative studies about rail dampers were conducted to show noise reduction of about 2 to 6 dB when the damped track is used with a soft rail pad, even if the rail roughness is relatively high [53–55].

An experimental study that set out to determine the effectiveness of rail dampers was presented within the scope of the STARDAMP project[56]. Two applied methods which are included short (6 m) and long rail (32 m), and their variations with undamped, damped (with rail pad), and damped (without rail pad) tracks and monobloc sleepers. For all variations, lateral and vertical decay rates were measured concerning EN 15461:2008 standard. The results show amenable values for freely supported rails between 300 Hz and 5 kHz. In low frequencies, long rails are reasonable, whereas in the vertical direction, short rails demonstrate higher decay rates in 800 Hz and 2 kHz, and it was stated as competent material for most applications.

In the same perspective, another experimental study was conducted to evaluate the acoustic performance of rail dampers to set a standard. The same length of rails was used in three methods with two different damper types (Damper A and B);

- Long rail is measured from frequency response functions
- Short rail with modal properties
- Short rail, the point and transfer frequency response functions on which both ends of rail from directly.

The predicted sound power levels for the undamped and dumped track (with soft rail pads-120 MN/m) when the train speed at 120 km/h show the noise contribution through vertical vibration is higher than the lateral direction at all frequencies values. For a damped track with a short rail method, the lower contribution was observed from the rail because of the dampers. Total power sound level attenuation was due to rail in vertical and lateral directions at 6.1 and 10 dB, respectively, and on the whole acoustic power was reduced by 3.7 dB. With the change of a much stiffer rail pad (820 MN/m), total power sound attenuation was 1.6 dB, and for all track components, which includes the sleeper is 4.2 dB [57]. As is also understood from the studies mentioned above, the noise reduction ability of rail dampers is related to the stiffness properties of rail pads. Rail pads also will be mentioned later in this section.

In an attempt to improve the properties of rail dampers, tuned rail dampers were developed and tested on the different railway networks in the world since the ’90s. An example of a tuned rail damper can be seen in Figure 2. The presented tuned rail damper consists of multiple resilient layers that were used to achieve clear oscillation mode in vertical and lateral directions. The presence of gap filler which is located at the mounting interface provides different characteristics under static and dynamic conditions. Under static load, it behaves as a flexible solid by filling the gaps at interfaces, and under the dynamic train, the pass-by condition behaves like a stiff solid. In both cases, vibration energy can be transferred from the rail to the dampers. Furthermore, resilient buffer layers that are assembled at the damper protect mounting instruments when the vibration is very high. As a matter of fact, from the test results, some improvement can be observed in terms of the track decay rate. Hence, reduction in rail vibration by 10 dB and overall noise level by 3.5 dB [58].

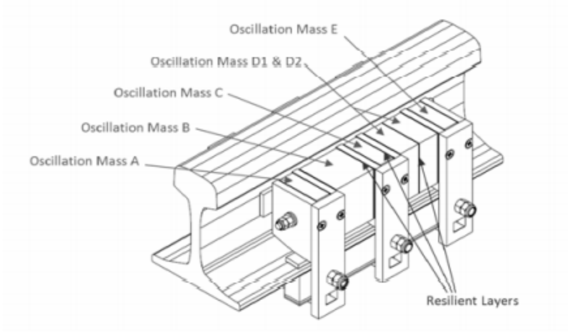

Figure 2. Isometric view of tuned rail damper [58]

A seminal study comparing the three typical design dampers should be examined to understand the noise reduction mechanism of rail dampers for high-speed trains. Monolayer, multilayer, and labyrinth constrained damped rails are manufactured from rubber, steel, and aluminum with particular thickness, as shown in Figure 3. In order to determine the vibration and acoustic properties of dampers, finite element (FEM) and boundary element (BEM) methods were used together with equivalent excitation for models. The equivalent excitation models were applied to the conversion of the wheel and roughness parameter to wheel/rail interaction forces. The results from the calculation show with damping rails, vibration amplitude reduction can be achieved. Monolayer and multilayer types demonstrate likely features of noise reduction. With a higher track decay rate (0.2 dB/m) and lower radiated power on average than others, the labyrinth type was suggested by researchers due to its track decay rate if its damping layer thickness is 5 mm [59] .

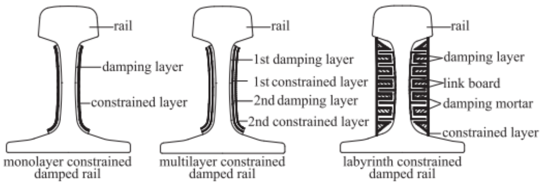

Figure 3. Monolayer, multilayer, and labyrinth constrained rail dampers [59]

Previous research has established that based magnetic behavior of materials used in rail dampers. For the purpose of increasing the rail damper working frequency range, magnetorheological rail dampers have been developed and examined with regard to the repression of rolling noise in terms of rails. Magnetorheological elastomer (MRE) rail dampers are composed of an MRE layer that includes silicon rubber and carbonyl iron, a plastic plate, two coils (upper/lower), and steel mass. MRE layer works as a spring with adjustable stiffness incorporated into coils which are produced a magnetic field. Tuning frequency should be regulated as regards rail vibration magnitude peaks to control the stiffness of the damper. The results obtained from the calculation of track decay rate can be compared for different variations of rail damper treatments below Figure 4. In contrast, the rail without rail damper was taken as reference, and others represent rail dampers with excited some current values and named as passive dampers. In addition, the controlled rail damper can be seen as a red line. TDR behavior of all dampers almost at the same values below 500 Hz. Furthermore, the current excited passive rail dampers are highly effective between 800 and 1200 Hz, and the controlled one has more significant TDR than all of the others. These findings suggest that using magnetorheological materials for rail damper applications can be the best option in the future [60].

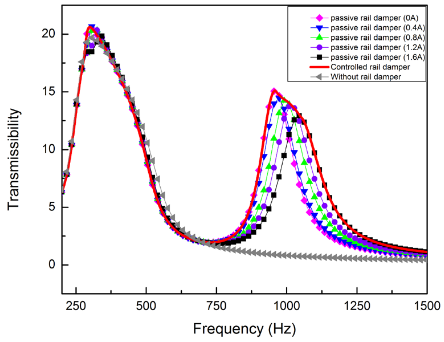

Figure 4. Estimated TDR for untreated rail and damped rails[60]

Another study with a detailed examination of slotted stand-off layer rail dampers in terms of material properties and design was conducted recently. Polyurethane/vinyl ester resin interpenetrating polymer network (PU/VER IPN) materials were used to produce rail dampers at different structural design aspects (slotted or semi-slotted). Afterward, the manufactured rail dampers were applied in the test section to evaluate TDR and rail radiated noise. With calculated and collected data, the contrast was made between rails with and without rail dampers. In the sense of material science, the convenient ratio of PU/VER was achieved at 80:20 with butyl methacrylate (BMA) and VER comonomers to obtain optimal rail dampers. The results obtained from test fields increased the vertical and lateral TDR when the slotted or semi-slotted dampers were applied. Also, a significant reduction of noise level was managed up to 6 dB in 1/3 octave band center frequency region between 250 Hz and 5000 Hz. The paper suggests that the semi-slotted rail dampers have important noise and vibration reduction characteristics; however, the life cycle of polymer-based rail dampers when their use in real conditions should be studied in broad terms [61].

The stiffness of pads was calculated in terms of temperature with the measurement of TDR similar to rail dampers. For natural rubbers, stiffness also can be changed based on the temperature. In other words, the rubber becomes more rigid at low temperatures and softest at high temperatures. Hence, between these temperatures, the highest damping loss factor and TDR can be obtained 54. With acoustic shielded rail and added on porous material as internal part, rail pads behavior was identified at 100 km/h speed freight train by FEM and BEM methods due to estimating rolling noise with TWINS. At the modeling stage contribution of gaps or non-gaps around the fasteners was considered. The results show that shielded rail with soft pads causes a 2.5 dB reduction in total sound power level and stiff pads only 1 dB [63].

3.2. Noise barriers

As a passive mitigation measurement, noise barriers have been widely used in railways and road traffic to reduce noise pollution for fifty years. For this purpose, some materials were developed and used, such as concrete, metal, or composites[64].

The existing literature on noise barriers is extensive and focuses mainly on sound absorption and airborne sound insulation characteristics called intrinsic properties. Besides these, according to

European Standards (CEN/TS 1793-5), barriers should be taken into consideration acoustical, mechanical and safety, long-term performance, and sustainability [65]. Moreover, the acoustic performance of noise barriers depends on some parameters such as materials, thickness, location, and density [66].

In addition, the height of barriers can be adjusted as low or high scale. The low height barriers are placed pretty close to the track, and they provide an effective reduction of rolling noise. Concerning security and visual aesthetic issues, low height barriers can be found more useful than higher. A study was conducted about low height barriers that consist of sonic crystals. The new type of low noise barrier was developed and examined for tramway rail lines which are used in the urban region. Cylinder-shaped resonant scatterers at different radii were fixed in a 1x1 structure. In the rigid box form, the inner cylinders (1. and 2. Band) have cavities, and they were covered by absorbent materials (glass wool), and the outer joined cylinders are in rigid form. Another type has rigid cavities without absorbent materials. Due to this design, the first and second band makes more absorption and lower reflection. After performing 2D BEM to make numerical simulations, the results show in the rigid cavity case, insertion loss can be reached 9 dB (A), and in the covered case, this number is 13.9 dB (A). Also, road traffic implementation gave similar results, but this is not related to our topic [67].

An experimental study was conducted to determine the productivity of low barriers that are modified with and without absorbers to offer more wayside noise reduction. With this design, three different types of low barriers, shown in Figure 5, were tested in field and laboratory scaled environments in RTRI (Railway Technical Research Institute-Japan) anechoic room with a 1/20 scale model by using ¼ inch single microphone located at different points. According to scaled model results, in the absence of absorbers, type-A barriers can reduce noise more than type-B, but inverted L + T type barriers are the most effective for reducing this case. In the presence of absorbers, barrier height directly affects the noise reduction capacity. Namely, 0.5 m inverted L + T type barriers can attenuate noise more than type-A barriers; on the contrary, when 0.9 m barriers are used, vice versa. The noise reduction level of absorbers is about 1 to 4 dB. For the field tests, a diesel locomotive was used in the RTRI test line at 30 km/h speed with four different scenarios, including two height barriers with/without absorbers and no low barriers fixed at 13 measuring points. As absorber material, 50 mm polyester fiber was used, and an A-weighted sound pressure level was measured. The field test results show the decreasing sound pressure level depends on the measuring point and the measured values of the field test approximately fall by half of the acoustic tests. For instance, in Case 1, when barriers height was 0.9 m, flat type-B barriers acoustic test noise reduction was 8.2 dB, and field test was 4.3 dB. Generally, inverted L + T type barriers were very effective than other types, even if they had the same height and lack of absorbers [68].

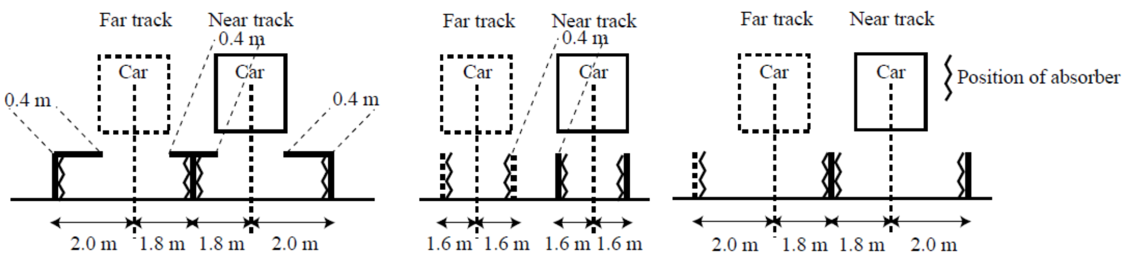

Figure 5. Low noise barriers and their locations [68]

Y-type noise barriers modified with modular absorbent materials and diffracted edges were introduced and investigated for high-speed railway operations from the shape perspective. The reflective reference barrier (NB1) and the other five configurated barriers were tested at TGV (France) line to measure LpAeq, tp at 25 m from the center of the rail line and 3.5 m height from the railhead. From the measurement results, the absorbent materials had a great effect on noise reduction. At 320 km/h, speed reduction reaches 6.5 dB (A) due to 5 dB (A) comes from absorbent [69].

Similarly, inclined T and Y shape barriers were investigated that were converted from conventional barriers for optimization purposes. Various parameters were taken into account to obtain maximum effective noise barriers, such as inclination angle, edge disruption angle, the height of barriers, and edge length. By using the Steepest Descent Method optimization process was carried out, and the modeling stage was made by SOUNDPLAN software. Sound signals were created in the test room at four different speeds/heights, and noise reduction was determined on an average logarithmic scale. Tests explain that increasing the optimal angle depends on increasing barrier/source distance and length of edges. After that, field measurements were conducted with 5 m height barriers and optimized angle evaluated around 20° for not shaped barriers. Also, the T-shape barrier optimization angle was found as 70° in the modeled case study with SOUNDPLAN. When it was made, the comparison between conventional and optimized barriers 7 dB (A) noise reduction can be achieved by the optimization process [70].

Sound reflection properties of noise barriers were examined via three different study methods: acoustic measurement, analytical calculation, and FEM simulation. The reflection Index (RI) spectrum was obtained from a fixed absorber on concrete and then with a real barrier system between 100 and 5000 Hz. In the first case, the absorber materials were located in front of a concrete layer with three air gap layers (0, 59, and 79 mm). The results from the three methods prove the similarity of analytical and numerical methods. The following experiment with noise barriers which is defined as cassette-element-based aluminum materials, were used for the backplate and front plate in perforated form. Acoustic measurement was implemented according to the aforementioned standard, which is related to the calculation of the reflection index and sound insulation index [65]. In the analytical model, the backplate was accepted as a reflective boundary; conversely, for FEM simulation was modeled as an oscillating plate. Therefore, in the high-frequency region (>2000 Hz), the simplicity of the analytical model has caused misleading results. Perforated front plate gains importance above these frequencies. On the other hand, in FEM simulation, the perforated layer can be modeled into mesh form and evaluated at high frequency. The significant contribution of this study is the developed FEM model for the calculation of RI when the noise barriers are at the design stages [71].

3.3. Sound and vibration absorbing structures

Concrete and cement-based materials are preferred for railway track structures due to their durability, cost-effectivity, and sound-absorbing characteristics. Sleepers, slab tracks, and tunnel lining materials made from concrete can be given as examples. The design of these materials is based chiefly on sound absorption capability and surface shape properties that were aimed the efficient acoustic structures. As a relatively new technique, concrete slab tracks have some advantages, such as direct fixation, low maintenance, and robustness [72]. On the other hand, the wayside noise is higher at 3-4 dB than the conventional ballasted track. In order to reduce the wayside noise for slab track systems, porous concrete sound absorber panels have been introduced and examined over the last two decades [73].

Porous cement-based materials have a significant number of voids or pores in nature. By means of these voids, propagated sound waves that come from rolling noise are absorbed in materials, and emitted noise is decreased. These types of composites have been developed and tested both in a laboratory and in real conditions. A remarkable study test results show noise reduction coefficient and acoustic absorption coefficient were maximum when the aggregate type was expanded perlite with polypropylene fibers. Compressive strength, void ratio, the thickness of the slab, and wind resistance parameters were taken into account for minimum requirements. As a result, concrete reinforced with fiber in slab form provided the reduction of pass-by noise by around 4.05 dB when train speed at 200 km/h [74]. Similar to this study, a theoretical and experimental investigation was conducted to determine the acoustic properties of newly designed sound absorber concrete composites. For obtaining high-performance sound absorbable concrete, cellulose fibers were used for reinforcing, and zeolite was used as a coarser agent that directly influences the sound absorption capacity. The minimum requirements of the parameters mentioned above were satisfactory, and also, in terms of durability, freeze-thaw resistance is remarkable for this design [75].

In addition, polymer concrete materials were developed for increasing mechanical properties and acoustic absorption characteristics. In a scaled model study, carbon fiber reinforced polymer concrete (CFRPC) was applied to reduce noise and vibration in ballasted tracks for both slab and sleepers. After performing the impact hammer test, the noise level reduction reached 4 dB when CFRPC were used as sleepers [76].

An experimental study [77] that was proposed for absorbing rolling noise in tunnels promised more than 10 dB reduction in 500-2000 Hz frequency interval by noise absorber panels. The absorber panel was built as a cylindrical shape that was trimmed and oriented to the noise source. Similar to this study, a plastic tube-like absorber was investigated experimentally and numerically to determine the acoustic properties by using commercial software COMSOL at 0-8000 Hz frequency intervals. The padded plastic absorber provided the average reduction in noise of 18.81 dB with the experiment and 20.13 dB with COMSOL Multiphysics® [78].

Dynamic vibration absorbers have been developed and used for both railway vehicles [79,80] and track systems [81,82]. A recent study about the mitigation of noise and vibration of the ballasted track using a dynamic vibration absorber (DVA) located under the track was remarkable. The DVA structures were fixed in parallel relative to each other under the rail. It was configurated with a steel mass bar, an elastomeric pad, and a disc spring, as can be seen in Figure 6. Negative stiffness of the absorbers was provided by the disc spring when the load was applied. Numerical simulations were implemented for continuous and discrete models to determine the noise and vibration decrement capacity. The continuous model has moderate superiority over the discrete one [83].

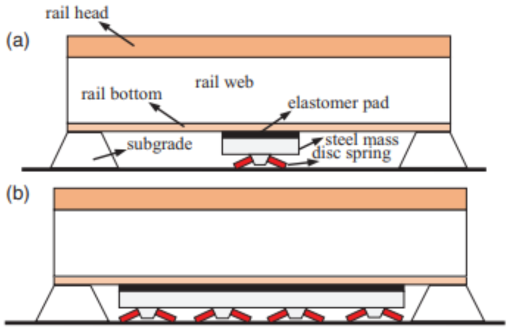

Figure 6. DVA structure along the track a) discrete arrangement and b) continuous arrangement [83]

3.4. Rail grinding

As a maintenance process, rail grinding is used to remove corrugations on the railhead to obtain a smooth surface to make the railway safer and silent with reducing rolling noise levels. The grinding process comprises some parameters such as the angle of the grinding stone, pressure, and the speed of the grinding train. Numerous studies have attempted to explain the role of rail grinding for referring [84–89]. Modern rail grinding techniques do not aim only at treating of corrugation at the rail; also, preventive measurements are the desired goals [90]. Generally, it is based on experiences and intuitive knowledge [91].

The importance and impact of rail grinding on reduction levels and railway nearby residents were investigated comprehensively in Germany at two stages. Firstly, the measurement was performed before and after rail grinding. Secondly, the people who were affected by the noise were informed in one state and in other states were not. The prospective abatement of noise level is approximately 2-3 dB (A) at total noise. With new and smooth wheelsets (ICE and the like trains), rail grinding results were at a significant level for both measurement areas. For example, in disc-break passenger trains, the reduction changed from 5 to 7 dB (A) but was about only 1 dB (A) for a rattler. In the second stage, the disturbance level of residents is defined by the surveys [92,93].

The newly developed rail grinding method was employed to prevent over noise emission after the grinding process due to rough surfaces in both laboratory and test fields. The test bench was installed with the fixed grinding machine for the lab-scale process instead of the vertical lathe machine place. The material was annular shaped and made of 58CrMoV4. An optical laser sensor was located on the mechanism to measure the roughness during the treatment. In an attempt to validate test bench results on the actual track, three sections were used at different rail grinding train speeds. Two-step treatment includes a large amount of removal material by roughing cut implementation and finishing procedure for obtaining highly smooth surfaces in both test bench and tracks. Without finishing, the roughness wavelength values exceed 100 µm, and this only can be overcome with running of trains for 5 and 20 weeks on the railway. Before the grinding, 11 train sets were measured in terms of acoustically, and 12 train sets after the process. The reduction of noise was achieved at 2 to 6 dB (A) for the overall noise level [94].

Finally, the cost-effectiveness of rail grinding is an essential issue for railway operators. In an aim to decrease the cost of the rail grinding process, a mathematical model was developed in recent research. According to this model, rail surface roughness, which is prompted by corrugation, was divided into three time periods. Fitted functions of growth curves were stated with respect to accumulated passing tonnage or time. The roughness data was collected from the mainline track regularly, and the model was initiated when the last grinding was done. Eventually, the operably and cost-efficient grinding schedule was derived from trials, in particular, to reduce tamping costs for ballasted track [95].

4. Conclusion

According to the decision of the European Parliament and the Council, 2021 was declared the European Year of Rail. In this context, the railway will gain even more importance in the coming days to achieve more sustainable and eco-friendly transportation modes.

This study set out to improve a better understanding of rolling noise mechanisms and mitigation measures. For this purpose, the selected studies from the literature about the track-related noise abatement methods were examined and reviewed over the last decade. The noise and vibration of the railway, which comes from many sources, had been experienced for long years by one of the authors who had worked as a senior train driver. As can be seen both in this paper and in the literature, noise mitigation methods are not efficient when they are not applied together. For instance, the rail damper provides the best attenuation with the proper rail pads. Also, with the combination of vehicle-related and track-related measures, better results can be obtained. Moreover, the use of plastic waste materials should increase in railway infrastructures and vehicles.

More new designs and studies would help us to understand deeply noise generation mechanisms and how they can be controlled on the source.

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