



Field-testing of noise abatement measures

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ABSTRACT

The strengthening of rail transport must be accompanied by a reduction in emissions. Regarding acoustics, innovative measures to increase noise protection must therefore be developed and investigated. Nevertheless, the determination of the sound reduction effect of mitigation measures on the railway infrastructure or in the propagation path is not yet standardised. There is a need for the development of a measurement and evaluation procedure, which is practice-oriented, reliable and allows the assessment of innovative measures in approval procedures. The German Centre for Rail Traffic Research (DZSF) at the Federal Railway Authority - an independent, scientific research facility of the German Federal Government - will support these activities. In addition to theoretical investigations, the Open Digital Test Field, which is being set up by the DZSF between Halle (Saale) - Cottbus - Niesky, is available for practical tests. Before starting the field tests, measurement procedure and boundary conditions are to be defined. The requirements and methods for quantifying mitigation measures formulated in previous research projects are outlined and reviewed.

1. INTRODUCTION

The German Centre for Rail Traffic Research (Deutsches Zentrum für Schienenverkehrsforschung – DZSF) is a technical-scientific departmental research institution of the Federal Ministry for Digital and Transport founded in 2019. At the DZSF, rail transport-related topics are investigated in order to strengthen rail transport through application-oriented research.

The DZSF is developing the Open Digital Test Field (ODT) for rail transport research as part of its research infrastructure on the rail network between Halle (Saale) - Cottbus - Niesky [1]. The Lärm-Lab 21 will become an integral element of the Open Digital Test Field.

The aim of LärmLab 21 is to expand the portfolio of measures for noise and ground-borne vibration abatement that are suitable for railway use and ready for application. With LärmLab 21, earlier federal initiatives for the testing of innovative mitigation measures will be continued and further developed. The focus of LärmLab 21 is on acoustic investigations and testing in real operation. In addition, other topics such as the development of application maturity, the migration of noise abatement measures and their acceptance will be considered.

Based on a detailed literature study, the requirements and the procedure of the experimental determination of the effect of sound and vibration measures are presented and discussed. The implementation is part of the planning of the LärmLab 21.

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2. TYPES OF ABATEMENT MEASURES AND PREVIOUS FEDERAL INITIATIVES

For more than a decade, the federal government's noise protection programmes have included the testing of innovative technologies on a real scale. Within the framework of the Konjunkturprogramm II (KP II), innovative measures for noise and vibration protection on the track were tested in real operation from 2009 to 2011 [2]. For the testing and evaluation of the measures, basic requirements for the verification measurements were developed [3]. Successfully tested technologies were included in national regulations for the assessment of noise exposure from railways in 2014 [4].

Following KP II, further noise abatement technologies were tested in 2013 and 2014 in the special programme “Sonderprogramm Lärmschutz Schiene” [5] and between 2016 and 2020 in the initiative “Initiative Lärmschutz-Erprobung neu und anwendungsorientiert” (I-LENA) [6].

Noise and vibration abatement technologies can be classified into the following categories:

- (a) Measures in the airborne sound propagation path: noise barriers of different materials, low height noise barriers, barriers with various edge shapes and photovoltaic installations,
- (b) Measures on the track / near the track to reduce rolling noise: rail dampers, rail shielding, rail treatment processes (grinding), rail coating, new rail profile,
- (c) Measures to reduce vibrations and secondary airborne noise: under ballast mats, soldered under sleeper pads, new sleeper type,
- (d) Measures on railway rolling stock: e.g. wheel dampers, brake block types,
- (e) Measures for specific track elements or railway facilities:
 - Noise in curves: rail lubrication, rail web dampers,
 - Impact noise: Removal of insulating joints, movable switch frog,
 - Bridge noise: e.g. highly elastic rail fastening, under sleeper pads, bridge dampers, anti-drumming foil,
 - Noise from shunting yards: Friction modifier track brake.

The outlined measurement principle and procedures in this paper will focus on measures for noise reduction of type (a) and (b) with comments on vibration reduction measures (c), where possible. Measures on railway vehicles and for specific track elements are not considered.

3. MEASUREMENT PRINCIPLE

3.1. Determination of the insertion loss

The overall aim of the measurements is the determination of the insertion loss (IL) of the investigated noise or vibration protection measure. The insertion loss is the reduction of noise or vibration level at a given receiver location due to installation of a mitigation measure directly at the source or in the path between the source and that location. For the determination of the IL a measurement procedure was developed in the course of the KP II-programme [3], which was refined and reviewed over time [7]. The basic principle includes measurements before and after the installation of the measure at a test section and a reference section, see Figure 1.

Unlike in laboratory measurements it is very difficult to ensure the equivalence of boundary conditions and excitation in the field test. Therefore, a single Before/After-procedure or Left/Right-procedure was found to be insufficient because changed environmental conditions (meteorology etc.) or a changed excitation by regular railway traffic must be corrected.

The insertion loss is defined as

$$\begin{aligned}
 \text{IL} &= (L_{\text{ref},A} - L_{r,A}) - (L_{\text{ref},B} - L_{r,B}), \\
 &= (L_{\text{ref},A} - L_{\text{ref},B}) - (L_{r,A} - L_{r,B}).
 \end{aligned}
 \tag{1}$$

$$\tag{2}$$

Eq.(1) represents a corrected Left/Right-comparison, eq.(2) represents a corrected Before/After-comparison and follows by rearranging eq.(1). A positive IL means a reduction of the noise or vibration level at the receiver L_r by the mitigation measure. Eq.(1) can be found identically in [8, p. 19] as well as with other indices in [7, p. 38].

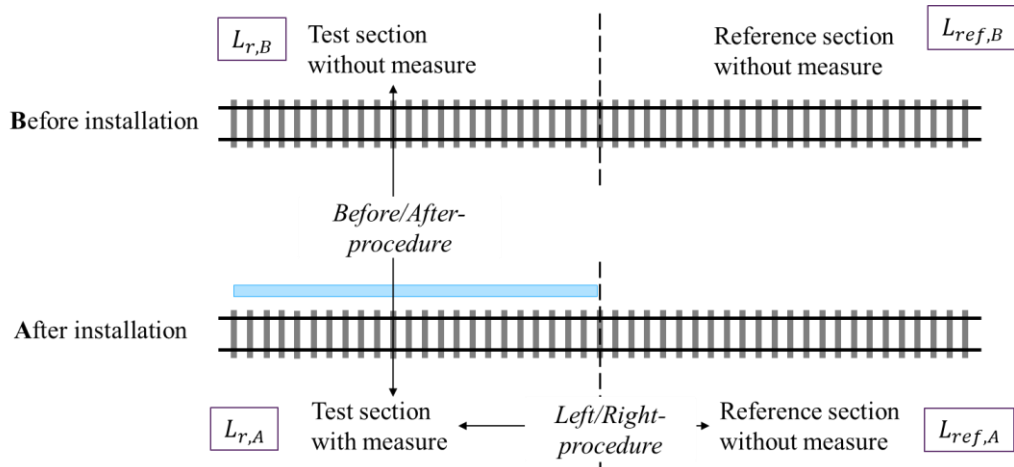


Figure 1: Basic principle of the measurement procedure based on KPII-specification [3]

A crucial information are the reference values, which allow for a correction of the effect measurement. The type of reference value may depend on the type of measure.

For noise barriers as measures in the transmission path (a), the technical specification CEN/TS 16272-7 [8] applies a similar test scheme as outlined in Figure 1. The reference values $L_{\text{ref},B}$ and $L_{\text{ref},A}$ are measured before and after the installation of the barrier at the test section, but directly above the noise barrier in a sufficient height, where the influence of the barrier is assumed to be negligible. In this way, the equivalence of sound source and environmental conditions is ensured. The calculation of IL follows from eq.(2). This is the “direct method”. Only, if the measurement $L_{\text{ref},B}$ is not available at the measuring cross-section, both Before-measurements are done at an alternative measuring site. This is called the “indirect method”. The equivalence of both sites has to be shown.

This “indirect method” was applied in a measurement campaign in the Netherlands for a low height noise barrier with diffractor on top [9]. Reference microphones in 2 m height and close to the track were used to confirm an almost identical noise emission at the two measurement sites. However, a correction of the measurement results with $\Delta L = L_{\text{ref},A} - L_{\text{ref},B}$ is not reported. The same noise barrier was also tested at a slightly greater distance from the track using the KPII-method (see Figure 1) in Germany [10]. At receiver locations close to the barrier, deviations of the IL up to 3 dB between the two campaigns are reported. The IL at more remote receiver locations is very similar.

An interesting modification of the KPII-method is described for the measurement of the IL of a noise barrier on a bridge [11]. Since the receiver locations are situated at a great distance from the test track section on the bridge (135 m – 170 m), meteorological influences on the measurement results during Before- and After-measurements cannot be excluded. Therefore, additional reference positions at the reference section were introduced, which are located at similarly far distances from



the track. The level difference between the near and far reference positions as the trains pass is monitored during the Before- and After-measurements and used to correct the meteorological influences on the effect measurement at the receiving positions.

For all measures that work directly at the track [(b) and (c) in sec.2], there is no uninfluenced reference position in the test section. In this case, the reference values must necessarily be determined in a reference section.

An interesting example for the determination of the insertion loss of a measure close to the track is the measurement campaign for rail web shielding in [12]. The rail web shielding was installed on two different test sections, which were equipped with different rail pads. Test section 1 as well as the reference section were fitted with stiff rail pads, test section 2 with soft rail pads. With the combination of Before/After- and Left/Right-measurements for all three sections, as proposed in Figure 1 and eq.(1)/eq.(2), the insertion loss of the rail web shielding was properly identified for the different types of superstructure. Remarkably, the IL of the rail web shielding depends strongly on the initial situation in terms of track decay rate.

In the area of ground vibration, the specification DIN SPEC 45673-3 [13] addresses the described procedure in chapter 5.5.3 “Before/after method with control cross-section” proposing an evaluation of the IL according to eq.(2). When using a Left/Right-procedure, it is required to determine the transmission admittances between track and receiver location and use them to evaluate the measurement results.

The relevant measurement parameter for airborne-sound is the pass by noise as A-weighted equivalent continuous sound pressure level $L_{PAeq,TP}$. EN ISO 3095 [14] forms an established guideline for the measurements of pass-by noise with regard to environmental conditions, requirements for equipment, measurement performance and evaluation.

Referring to measurement of ground vibration, the measurement parameter is the overall rms-value of the vibration velocity at the receiver positions $L_{v,TP}$. ISO 14837-1 [15] represents a general and Deliverable D1.2 of the RIVAS-project [16] a more specific measurement guideline.

3.2. Equivalence of sound and vibration source

For a valid determination of the insertion loss, the sound or vibration source for the Before- and After-measurements must be equivalent, i.e. the properties of the sound source must be sufficiently similar for the measurement uncertainty to be acceptable. Obviously, a source equivalence can be achieved more easily in a Left/Right-procedure with adjacent test and reference sections.

In most cases, regular railway traffic serves as the sound and vibration source. Equivalence must be ensured by several requirements. Firstly, the vehicles should be as similar as possible, the operating parameters must be controlled and the sound sources must be monitored at the reference position.

Regarding the rolling stock, the KPII-method [3] refers to the specifications in DIN 45642 [17]. Trains must be categorised into different train types and speed classes and for each train category, a minimum number of trains must be recorded: passenger trains with disc brakes (min. 10 trains), passenger trains including at least one car with brake blocks (min. 15 trains), freight trains (min. 20 trains), light rail vehicles (min. 15 trains). CEN/TS 16272-7 [8] specifies the same train type classification, but a uniform number of at least 10 trains for all train categories. In the cited examples of measurement campaigns [9], [12] and [18] the classification was done based on different series of passenger trains, which provides even more similarity. The number of measured train pass-bys varied, freight trains are often underrepresented. In the sense of a generalised statement on the effect of the noise or vibration abatement measure, an averaging over train categories is certainly useful. Averaging over all passing trains and all speeds is not appropriate because the location of the main noise source on the vehicle and the mechanism of noise generation vary with train type and can change

with speed. Freight trains show the greatest variance and require a larger number of samples to achieve a higher accuracy level for the IL estimate. It is widely reported that it is important to remove individual train outliers from the averaging process in order not to distort the result, e.g. [7], [18]. Outliers can be trains with wheel flats or other condition defects.

The specification CEN/TS 16272-7 [8] also defines two other types of sound sources to ensure the equivalence regarding Before/After-measurements: the usage of one or more specific test trains or an “indirect” excitation with a loudspeaker. The loudspeaker shall generate a rail traffic noise spectrum according to EN 16272-3-2 [19]. Figure 2 shows a comparison of noise spectra of different train types. In general, the standardised spectrum reproduces the maximum noise emission in the range of 1000-2500 Hz. The lower frequency components of the noise emission spectrum of freight trains are also well represented. This alternative sound source can only be used for testing noise reduction measures in the airborne sound transmission path and should be only used to represent rail traffic with maximum speed of 200 km/h.

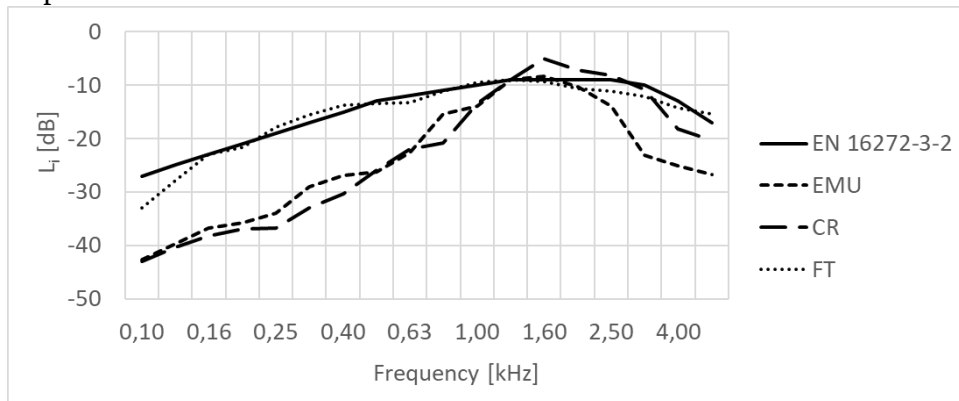


Figure 2: Comparison of normalized noise emission spectra of different train types: — standardised rail traffic spectrum acc. to EN 16272-3-2 [19]; ---- electrical multiple unit (“S5” in Fig. 3 of [18]); — · — passenger trains with cast-iron brake blocks (from Fig. 16 of [20]), freight trains with cast-iron brake blocks (from Fig. 16 of [20]).

The train speed is the main operational parameter, which needs to be controlled for the pass-by measurements. The specification of the KPII-programme [3] and CEN/TS 16272-7 [8] define a tolerable deviation of the speed from the mean value within a speed class of ± 5 km/h for speeds above 100 km/h and of ± 5 % for speeds below 100 km/h. The requirement is thus stricter than in EN ISO 3095 [14] for the acoustic type test of railbound vehicles.

3.3. Equivalence of test and reference section

A close match of the acoustical boundary conditions at test and reference section allows for a valid evaluation of the Left/Right-measurements. This applies to environmental conditions, including terrain profile, ground surface and weather conditions. The same vibration transfer function from the track to the surrounding area would be ideal. For the railway line, a uniform track layout and nearly identical and homogeneous superstructure are prerequisites. Test and reference sections should therefore be adjacent to each other.

Rolling noise depends substantially on the rail roughness and the track decay rate. Both track properties need to be recorded as part of the measurement procedure. The acoustic rail roughness on all measurement sections should be below the limit curve of EN ISO 3095 [14] to ensure a minimal contribution of the rail roughness to the combined roughness of rail and wheels. In the KPII- and I-LENA-specifications the differences in rail roughness are limited to 1 dB in all octave bands, which

may be difficult to fulfil. Reports on measurement campaigns, on the other hand, show that the pass-by noise level $L_{pAeq,TP}$ at the different sections, measured subsequently with the same vehicles can be within a variation of 0.2 - 0.6 dB if the above requirements are met [12], [18].

In [7], Gerbig et.al propose to correct the measured reference values L_{ref} by a correction term $\Delta L_{ref,r}(f)$, which compensates for a different rolling noise excitation due to a different combined roughness of wheel and rail on test and reference section. The correction term is derived by prognosis calculations with the STARDAMP-tool. The measured rail roughnesses are the variation parameter in the prognosis calculations. It is practically the application of the transposition method assuming that vehicle transfer function and track transfer function remain unchanged in the test and reference sections [21, p. eq. (2.2)]. This is an interesting option. However, practical validation is still required and the assumption of an unchanged track transfer function needs to be justified.

4. REQUIREMENTS FOR THE MEASURING SECTIONS

As discussed before, there is the need for strict requirements on the track, operation and environmental conditions to minimise the measurement uncertainty of the field tests. Among the hundreds of kilometres of track in the Open Digital Test Field we are looking for test sections that meet the following conditions:

- straight double-track with minor gradient and without elevation, preferably 1000 m length,
- ballasted track with concrete sleepers and welded rail without rail joints,
- no railway crossings, no bridges in the vicinity,
- identical, homogeneous superstructure on test and reference section.

Operational requirements are:

- constant speed throughout the entire test and reference section,
- line speed of at least 160 km/h.



Figure 3: Example of track section in the ODT with appropriate layout, length and propagation conditions

Requirements for the surroundings are:

- flat terrain, track is not located in a cutting and not on an embankment,
- no trench with or without water next to the track,
- free sound propagation within a 60°-sector on both sides of the line between microphone positions and track,
- no large reflecting objects within a range of 75 m around the microphones,



- comparable ground and meteorological attenuation in test and reference section,
- negligible background noise.

The number of requirements limits the range of suitable test sections considerably. After evaluation of GIS data and exploring the test field, a few spots could be identified, that will be examined in more detail in the future. Figure 3 shows an example of a potential test section in the ODT.

5. CONCLUSIONS

In the course of developing LärmLab 21 as part of the Open Digital Test Field, previous approaches and experiences in determining the insertion loss of noise and vibration abatement measures have been studied and surveyed. In general, the prior specifications used in German federal research programmes are still applicable. A few modifications regarding the measurement quantities and the proof of equivalence of test and reference sections need to be incorporated. The high level of agreement with other comprehensive measurement campaigns in the European region confirms the approach presented. The paper also includes some alternative reference positions and sound sources.

Measurement procedures for abatement measures for specific track elements as curves, switches etc. still remain to be elaborated. Similarly, a thorough review of measurement procedures for ground vibration mitigation measures is pending.

With its activities, the DZSF aims to prepare valid and practicable measurements in its own test field, but also to contribute to the European standardisation of measurement procedures.

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