Advancements in Noise and Vibration Abatement
to support the Noise Reduction Policy of Deutsche Bahn

B. Schulte-Werning, B. Asmussen, W. Behr, K.G. Degen, R. Garburg
Deutsche Bahn AG, Systemverbund Bahn, DB Systemtechnik, Munich, Germany

Abstract
The Environmental Noise Directive of the European Union requires the member states to produce noise maps and to establish action plans for noise reduction. This directive has been transposed into national law in Germany and directly affects Deutsche Bahn (DB) and its noise reduction policy. DB has set itself the goal of halving, by the year 2020, the level of rail traffic noise experienced by local residents in 2000.

As one of the major railway undertakings in Europe, DB performs continuous investigation to respond to public demand for railway traffic with low noise impact. The aspects of the reduction of the generation of noise are being tackled in several projects, mainly together with expert partners. Joint research projects provide a common knowledge base and strongly support the harmonisation of existing national rules and guidelines for train design and operation.

Thus, a research and development programme for a low-noise railway is under way at DB to treat the noise of the vehicles and infrastructure. The direct noise experienced by railway-lineside residents due to train movements on the track can be reduced by minimising the sound radiation directly at the source. This is the first-choice solution as it proves to be the most effective countermeasure regarding a cost-benefit relation.

This article describes three recent efforts of DB to develop a modern ruling for railway noise prediction and to reduce railway noise.

Introduction
The European Parliament and the Council have put into force the Directive on the Assessment and Management of Environmental Noise (“Environmental Noise Directive (END)” [1]), aiming at avoiding, preventing or reducing harmful effects of environmental noise on human health. END requires member states to produce “strategic noise maps” by using noise indicators assessing the number of people affected by noise, to inform the public about noise exposure, and to draw up “action plans” to reduce noise where necessary. The directive was transposed into German legislation [2] in 2005 and has tightened the requirements governing traffic noise abatement. In future, local authorities will have to set down action plans to prevent and reduce environmental noise based on noise-mapping results. Cost-effectiveness will play a crucial role when assessing the proposed noise reduction strategies.

In the CALM network [3], basic studies and assessments were performed to support END. To follow the EU requirements and to strengthen the environmental friendliness of European railway traffic, the European Rail Research Advisory Council (ERRAC) has defined and now maintains the Strategic Rail Research Agenda (SRRA) also in the field of “environment” [4]. The most prominent keyword relating to the environmental friendliness of railway traffic is noise reduction.

DB has responded positively with its self-obligation to decrease the environmental impact of railway traffic [5, 6, 7, 8, 9]. Among the seven central premises in the associated “Railway Agenda 21” of DB, it is stated that for sustainable mobility:
- the economically and ecologically successful railway creates the pre-conditions for the relocation of road and air traffic to rail,
- the quiet railway reduces the noise of rail traffic,
- the environmentally responsible railway protects nature and the countryside.

Deutsche Bahn takes its responsibilities seriously and has set itself the ambitious goal of halving, by the year 2020, the level of rail traffic noise experienced by local residents in 2000. If this target is to be achieved, all available noise abatement techniques need to be used.

The DB realizes the voluntary noise rehabilitation programme of the German government. With the introduction of this scheme, it became feasible to realize noise protection measures along existing sections of railway tracks. Meanwhile 100 Mio € have been made available annually for this programme to put up noise protection walls or noise proof windows. The implementation regulations for this noise rehabilitation programme are set out in the “Guidelines for promoting rail noise abatement measures” published by the Federal Ministry for Transport, Building and Urban Development [10].

Deutsche Bahn is aware of the effects that noise emissions from rail traffic can have. This is the reason why a noise reduction programme was initiated [11]. Efforts are being made to reduce noise at the source, i.e. from the vehicle itself or from the wheel-rail interaction. Having optimized the acoustic characteristics of new vehicles used for local and long-distance passenger services, major reductions in noise emission levels from freight wagons are now feasible. The novel composite brake block (known as “K-block”), which has undergone extensive testing, was recently approved for international use [12, 13]. Up to now, wheel treads were roughened every time the cast-iron brake blocks were applied. With this new development, the treads remain smooth - a fact which will lead to a reduction of 8 to 10 dB(A) in rolling noise.

DB has established a special rail care scheme called “Specially Monitored Track” in which noise radiation from the rail is regularly monitored by a custom-built sound measuring car [14, 15]. If the acoustic quality of the rail head surface is below a specified level, the roughness - i.e. short-pitch corrugations that occur on the rail head surface as a result of normal operations - is removed by grinding the rail head along these specially monitored track sections using a special technique.

The three further development activities reported on here follow the above-mentioned guiding principle to improve the noise reduction at the source. To take all available modern low-noise technologies into account in the prediction of residents’ noise reception and the dimensioning of noise abatement, an up-to-date prediction method is mandatory. Only by such a reliable and validated method all progress to reduce railway noise in urban traffic noise situations and to avoid excessive noise emission from bridges, which are often noise “hot spots” for the residents, can be made beneficial.

Recent developments in reducing railway noise in urban situations: SILENCE – an integrated approach

Substantial strategies and measures for noise reduction options are under development within the SILENCE project [16], where Deutsche Bahn has been involved as a major partner since the project was launched in 2005.

SILENCE is an integrated research project funded by the Sixth Framework Program of the European Commission and will terminate in 2008. It aims to develop an integrated methodology and technology for improved control of surface transport noise in urban areas. Issues covered are noise control at the source, noise propagation, noise emission, and the human perception of noise. “Integrated system” means the combined consideration of city authorities, individual traffic (on road) and mass transport (on rail and road) with a thorough treatment of all traffic
noise facets: urban noise scenarios, individual noise sources (vehicles), traffic management, noise perception and annoyance.

One key element of this approach is the global modeling for the prediction of noise effects on urban scenarios. Based on models for individual traffic elements developed in previous EU projects the global model predicts the overall noise emission of complex traffic situations and allows the prediction of noise perception by a source model coherent with the models used in the EU-funded project HARMONOISE [17].

Within SILENCE 15 partners from railway undertakings (Trenitalia, STIB, SNCF, DB), railway industry (ALSTOM, Ansaldobreda, Bombardier, CRF, LS, Corus, D2S) as well as engineering and academic institutions (ISVR, KTH, VTC, Deltarail) form a railway-related sub-consortium.

The railway-related activities are concentrated in two subprojects led by SNCF ("Railway Vehicles") and by DB ("Railway Infrastructure"), the latter focusing on development and implementation of efficient infrastructure-based noise reduction technologies.

Key work-packages are the validation platforms for trams and conventional rail. Their objectives are to clarify the state of the art by running assembled prototypes of state-of-the-art low-noise trains on low-noise tracks thus building a consensual prototype validation platform at the beginning of the project to identify the needs for further acoustical improvement and to run upgraded prototypes at the end of the project. Therefore DB’s major contribution to the project consists of conducting field tests in combination with extensive measurement campaigns.

In general there are two options to reduce rolling noise at source: (1) Minimization of contact forces by keeping the running surfaces of both rail and wheel smooth and (2) reduction of the intensity of the radiated sound field by increasing the damping of rail and wheel. The second option was followed within SILENCE (see Fig. 1). Particularly challenging is the goal to considerably further reduce the rolling noise of freight wagons equipped with K-blocks (which is considered to be state of the art within SILENCE) by adding dampers to the wheels. Unlike in the case of disk braked wheels, where dampers are known to be an efficient way to reduce noise emission by about 4 dB, wheel dampers for tread-braked wheels are not yet commercially available due to the high temperatures the wheel is subjected to during braking.

![Fig. 1: DB’s test track with rail dampers developed by Corus within the SILENCE project (left) and concept of the wheel dampers for freight wagons developed by Lucchini S.A. (right)](image)

A first measurement campaign with freight wagons equipped with K-blocks on a TSI-compliant track near the town Solpke on the high-speed line Hanover-Berlin in May 2006 demonstrated very clearly that rolling noise radiated from rail and wheel is the dominant noise source also in the case of wagons with K-blocks. Other noise sources as e.g. the superstructure of the coaches are negligible and, hence, further development has to concentrate on wheel and rail.
It is well-known that increasing the track decay rate by dedicated “rail dampers” attached to the rail web can considerably reduce rolling noise emission. A novel approach followed within SILENCE is that existing solutions for rail damping are to be optimized not only for noise reduction but also for reducing roughness growth. Over a long period of time, the noise level is dependent both on the noise for a given roughness and also the growing roughness level. The development of the rail dampers is being carried out by Corus Rail and is supplemented by extensive modeling and computer simulation performed by the Institute of Sound and Vibration Research at the University of Southampton. Rail dampers with an improved acoustic coupling to the rail web were installed on a test track near Augsburg (see Fig. 1). In an extensive measurement campaign in September 2006 all relevant parameters (sound pressure, rail roughness, rail vibration, track decay rates) were recorded. Noise reductions between 2 dB(A) and 4 dB(A) were recorded [18]. The mitigation effect of the dampers depends on train speed and on track stiffness. Computer simulation predicts that roughness growth on the rail head is slowed down considerably by rail dampers due to reduced rail/wheel contact forces. First measurements point into the same direction. DB intends to follow this effect in a long term observation of the test track.

Prototypes of the wheel dampers developed by Lucchini S.A.(see Fig. 1) were tested in another measurement campaign in September 2007. A total of 24 wheel dampers were mounted to the wheels of a test train with sliding wall freight wagons. Their noise emission was measured and compared to that of wheels without dampers. These tests were done both on rails with and without rail dampers. Fig. 2 shows a summary of the measured noise reduction obtained with rail dampers, wheel dampers and by the combination of both.

![Fig. 2: Measured noise reduction in dB(A) obtained with rail dampers for different train categories, wheel dampers and the combination of both.](image)

Elimination of micro-pressure wave induced noise radiating from tunnel exits

When a high-speed train enters a tunnel, a micro-pressure air wave is raised moving along the tunnel at the speed of sound. Under certain circumstances the rising edge of the wave front
becomes increasingly steeper on its path through the tunnel (see Fig. 3). At the tunnel exit the pressure wave is partly reflected back into the tunnel and partly emitted outwards. A more detailed discussion of the physical mechanism and the influencing parameters is given in [19]. The emitted part can be clearly audible even at distances far away from the tunnel portal.

Fig. 3: Evolution of the shape of a micro-pressure wave while propagating inside a tunnel.

During the test runs in December 2005 prior to the opening of the new high-speed line Nuremberg-Ingolstadt in Germany, clearly audible effects, perceptible as sonic boom, occurred at the tunnels Euerwang and Irlahüll when the test trains ICE S or ICE 3 entered the tunnels at the opposite entrance with speeds up to 330 km/h. Both double-tracked tunnels with a cross-section of 92 m² and a length of nearly 8000 m were built with ballastless track (slab track).

In regular traffic of European high-speed lines this phenomenon did not show up in the past due to the use of ballasted track and due to the specifications for length and cross section of the tunnels. In order to ensure the successful opening of the new high-speed line in accordance with Germany's national noise legislation and without creating unacceptable annoyance for residents and for people standing in close vicinity to the tunnel entrances (e.g. railway workers), DB decided to take immediate countermeasures by equipping the two tunnels with acoustical track absorbers (Fig. 4). These absorbers are designed to directly counteract railway rolling noise, but they also affect the pressure wave steepening process (for details see [19]).

Fig. 4: Photograph of the absorber elements on top of the slab track inside the tunnel

Extensive microphone measurements were carried out before and after the installation of the track absorbers. In particular the low frequency character of the “sonic boom” does not make the A-weighting of measured sound pressure levels the most appropriate filtering. In order to exclude annoyance in residential areas, different evaluations of the acoustic measurements
were performed [20]. For example, the C-weighted peak sound pressure level $L_{Cpeak}$ for the maximum train speed of 300 km/h at a distance of 5 m from the portal of the Euerwang tunnel is shown in Fig. 5. Before installation of the track absorbers, the lower trigger level $L_{Cpeak} = 135$ dB(C) of standard 2003/10/EC [21] was exceeded by up to 9 dB(C). After the tunnel was fully equipped with absorbers the maximum measured levels were clearly below this limit even very close to the portal.

![Graph showing C-weighted peak sound pressure level for different conditions.](image)

**Fig. 5** Maximum C-weighted peak sound pressure level $L_{Cpeak}$ of the micro-pressure wave for ICE 3-type trains with 300 km/h at a distance of 5 m to Euerwang southern portal. Left bar without absorbers; middle bar partly equipped with absorbers; right bar fully equipped with absorbers. For comparison: – – – lower trigger level $L_{Cpeak} = 135$ dB(C) of standard 2003/10/EC.

For future railway infrastructure projects, additional options for countermeasures are being developed. A quite large mitigation potential is expected from optimizing the tunnel portal construction, as is practised on most Japanese high-speed lines. In addition, optimization of the front construction of future high-speed trains should be taken into account.

**The DB handbook 80025 “Ground-borne vibrations and secondary airborne noise”**

During the passage of track-bound vehicles not only noise but also vibrations are generated at the wheel-rail contact point and transmitted via track and superstructure into the substructure, transferred through the ground (soil) and can generate noticeable vibrations inside adjacent buildings. Under certain conditions, the vibrating walls can act as noise sources and can radiate structure-borne noise. A high level of vibration and structure-borne noise leads to considerable annoyance of the residents and becomes a more and more serious problem for increasing traffic on rail infrastructure. In contrast to airborne noise, ground-borne vibration is not a common environmental problem for all sorts of traffic but a specific phenomenon for rail traffic caused by the steel rails in contact with the steel wheels.

Germany's national legislation expressly mentions vibrations as a potentially annoying or dangerous reception. As a consequence vibration emissions have to be predicted in the planning process when building new lines or when upgrading existing railway lines and their impact has to be assessed within environmental impact studies. If necessary, vibration mitigation measures have to be foreseen. In spite of this legal requirement, no well-defined limit values have been set by legislation. Additionally, the forecasting method is not clearly defined. This leads to considerable uncertainties and very often to litigation in the planning process.

Therefore DB is at present in the process of putting the DB Handbook 80025 “Ground-borne vibrations and secondary air-borne noise” into force as an internal directive [22]. It describes the
basics, necessary measurements and also the process for predicting ground-borne vibrations for construction and planning purposes.

This handbook is divided into five parts:

- General principles and fundamentals
- Measurements and prediction
- Evaluation of ground-borne vibrations caused by rail traffic
- Mitigation measures
- Vibrations in connection with construction work.

For the prediction, the guideline describes a spectral forecasting procedure, generally based on third-octave vibration-velocity spectra. In contrast to noise predictions, the reception has to be predicted at a point inside the building, so that all relevant characteristics of the building have to be known. The complete path of the vibrations from the track via the soil to the inside of the building is divided into several sub-systems:

- Source (emission system): Origin of the dynamic excitation from the concurrence of vehicle and track (in general the emission point is defined as 8m beside the nearest track)
- Transmission system: propagation of the vibration through the soil towards the building
- Reception system: the transfer function describing the effects inside two bordering buildings tackles the primary immissions (for example foundation vibrations) and the secondary immissions (vibrations of the walls and ceilings inside the building).

To describe the different sub-systems and transfer-functions, measurements, empirical values (e.g. from data-bases fed by similar projects) and special simulation and prediction tools are used. For good prediction quality, the boundary conditions such as the parameters of the vibration excitation have to be ensured and its dispersion chosen sufficiently precisely. The summary of the predicted vibration velocity level is obtained from the vibration-velocity level \( L_v \) for the emission and the different transfer-functions of the sub-systems, where each one is drafted in a third level diagram.

Based on vibration-velocity spectra, which have been determined in the way described, the KB values have to be calculated. KB is the frequency-weighted non-dimensional vibration-velocity (a definition can be found in the German standard DIN 45669 [23] and in [24]). KB is used in several European countries for the assessment of vibrations. Different KB values are common:

- KB\(_{F\text{max}}\) is the maximum value estimated within a certain period of time (day or night)
- KB\(_{F\text{TTr}}\) takes into account the frequency of occurrence of train pass-bys (separately for day and night period) and the duration.

For new lines, these KB-values can be evaluated with certain “thumb-rule” values. For existing and upgraded lines, normally for the evaluation of annoyance, the augmentation of vibration exposure level has to be determined. In the past, DB implemented several annoyance studies to find characteristic values which help to describe the disturbance level [25].

In cases where the forecasted values exceed the vibration limit values, some mitigation measures have to be determined. Usually “active” mitigation measures – which mean measures near the track system to prevent the occurrence or transmission of vibrations – are preferred but in some cases also mitigation measures within the path of transmission or connected to the buildings are the first-choice solutions.

Several established mitigation measures exist on the basis of additional resilient elements in the track. The optimum measure for a special situation depends on the frequency range of the excitation or the main peaks in the immission. If the maximum of the vibration emission spectrum is at very low frequencies (below 15 Hz) floating-slab track systems can be used very effectively. Ballast mats are effective when the maximum in the vibration emission or the needed mitigation at the immission point is at medium frequencies (15 to 35 Hz). These
mitigation measures are very efficient for railway lines in tunnels and DB has invested a lot in investigations and specific measures in the last few years (e.g. in connection with the new railway tunnel crossing the centre of Berlin [26] and other projects). For surface lines no similar effective measures are known. Sometimes sleepers with elastic supports (under-sleeper pads or USPs), are an alternative with moderate costs (compared to floating slab track systems and ballast mats) which not only increase the track quality but can also achieve a significant reduction in ground-borne vibrations and structure-borne noise provided the relevant excitation frequencies are above 40 Hz. USPs have the additional advantage that they are a retrofit solution (Fig. 6).

![Retrofit of old sleepers with new sleepers fitted with USPs with help of a rebuilt vehicle.](image)

**Fig. 6:** Retrofit of old sleepers with new sleepers fitted with USPs with help of a rebuilt vehicle.

DB has been participating in a UIC-funded project (UIC Project No I/05/U/4440 “Under Sleeper Pads”) in the last two years to share information and experiences with USPs in different fields of applications and to develop a first draft of a UIC leaflet. Measurements in conjunction with field tests in tunnels and on open lines have shown insertion losses of about 5-15 dB for frequencies above 50 Hz [27] (see Fig. 7).

It should be pointed out that USPs can have a (potentially negative) effect on air-borne noise emission. Measurements carried out at different locations have not given a consistent picture yet. Some measurements indicated a negligible effect while others recorded considerably increased noise emission. Further research is certainly necessary here.

In 2004, DB summarised its specifications for USPs in document DBS 918 145 [28], which is in use in the meantime in various countries so the technical and material parameters are determined by the same testing procedures and evaluation criteria.
Low-noise train on a real track: The LZarG Project

An important building block in DB’s national plan to reduce railway noise by at least 10 dB(A) until 2020 compared to 2000 is the “LZarG”-project (see Fig. 8), which was launched in December 2007. The outcome of this project will add notably to the effect of the federal noise rehabilitation programme and to the noise reduction by retrofitting composite brake-blocks to freight wagons. LZarG is funded by the German Federal Government and adopts the strategy to decrease the noise of trains by reducing the sound radiation at its origin, i.e. at the wheel/track interaction.
The structure of the project is shown in Fig. 9. It comprises the optimization of wheels, bogies and the track system. One subproject covers the wheel/track contact in detail with the aim to optimize the bogies of freight trains in order to find single low-noise components and to reduce the thermal stress on the wheels during the braking process. Minimizing the sound radiation of the wheels of regional trains and freight trains will be done by developing a new wheel shape design as well as wheel dampers within a second subproject. Also the disks of the braking system connected to the wheelset in case of regional trains will be taken into account. A third subproject will cover the acoustic optimization of the track system. This shall include damping devices mounted to the rail, under sleeper pads and the rail fastening systems. These three subprojects are combined in the part B “reduction of the rolling noise” and cover the technical aspects of the project. At the end of the project all improvements achieved will be evaluated in field tests with a test train on different track systems (content of subproject C).

In order to ensure that each development within LZarG is in agreement with the relevant regulations and the special requirements of rail traffic and in particular with the special needs of Deutsche Bahn including maintenance procedures a sub project A “System integration and implementation” was defined embracing the other parts “B” and “C”.

![Fig. 9: Structure of the LZarG project](image)

The project is intended to finish in 2010 and it is expected that the noise-reduction technologies developed will be available for regular use at the end of the project.

Conclusions

This article describes three recent efforts by DB to develop a modern ruling for railway noise prediction to reduce the generation of railway noise and the mitigation of vibrations. These projects will support DB’s self-obligation of halving, by 2020, the level of rail traffic noise experienced by local residents in 2000. To achieve this ambitious target, well coordinated implementation of state-of-the-art noise abatement techniques covering both vehicles and infrastructure is needed.

After completing the projects mentioned, DB will be able to use the end results to reduce railway noise significantly. The key results and deliverables are noise abatement techniques for rail vehicles and the infrastructure. Tools, methodologies and input data for decision support systems are available as well.
Acknowledgement

The SILENCE project receives funding from the European Commission, Research Directorate-General, which is gratefully acknowledged.

The LZarG project receives funding from the German Federal Ministry of Economics and Technology, which is gratefully acknowledged.

References

[19] Th. Tielkes, H.-J. Kaltenbach, M. Hieke, P. Deeg, M. Eisenlauer, “Measures to counteract micro-pressure waves radiating from tunnel exits of DB’s new Nuremberg-


[23] DIN 45669 Teil 1 „Messung von Schwingungsäimmissionen; Schwingungsmesser; Anforderungen, Prüfungen“, 1995


[27] R. Garburg, UIC Project No I/05/U/4440 Under Sleeper Pads, WP 3; Acoustics and Vibration, final report, July 2007


[29] Description of Work „Leiser Zug auf realem Gleis - LZarG“, BMWi-Verbundprojekt Förderkennzeichen 19 U 7020A, Projektskizze, 03.08.2007