Recent Developments in Noise Abatement at Rolling Stock and Track to support the Noise Reduction Strategy of Deutsche Bahn

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Abstract

Deutsche Bahn has defined a considerable reduction of noise from rail traffic as one of its strategic business objectives. The target is a global reduction of 10 dB(A) until year 2020 in comparison with year 2000. In order to reach this target and to respond to the growing public demand for railway traffic with low noise impact, DB has developed and implemented innovative solutions to reduce railway noise with the priority given to technologies minimising the sound radiation directly at the source. DB is also participating in national and European research projects with their R&D activities mainly being carried out by DB Systemtechnik, Europe’s biggest centre of excellence for railway technology.

A key element within this strategy is the ‘smooth wheel on a smooth rail’. More than 700 km of DB’s network now are ‘specially monitored track’, where regular monitoring and rail grinding is performed solely for acoustic purposes. Additional noise reduction can be achieved by increasing the damping of both wheel and rail.

As public sensitivity to the negative impact of vibrations emitted from rail traffic is growing, there is also a growing demand for innovative vibration mitigation technologies.

This paper gives an overview of recent efforts of DB to reduce noise and vibration and of current research projects with DB’s participation.

1. INTRODUCTION

Rail traffic is the most sustainable surface transport mode for regional and international transport both for freight and passenger movements. The forecasts for railway transport in Europe underline this approach. The Strategic Rail Research Agenda 2020 [1] of the European Rail Research Advisory Council (ERRAC) expects, in its Railway Business Scenarios, rail to double its share of both the freight and the passenger markets compared with 2000. However, noise and vibration are often perceived as weaknesses in rail’s environmental credentials. As the noise emission seriously affects the otherwise positive environmental balance of rail traffic and in order to respond to the growing concern of the population about the negative health impact of noise, Deutsche Bahn (DB) has defined a sustainable noise reduction as one of its strategic business targets. The building blocks for the implementation of noise reduction measures at DB are:

1. The German Federal Noise Abatement Law ‘16. Bundes-Immissionsschutz-Verordnung’ (16. BImSchV) defines strict upper limits (particularly during night time) for the average noise level at dwellings in the vicinity of those railway lines, which are newly built or which undergo major changes.

2. In order to reduce railway noise in cases of high immission levels along existing railway lines, the German federal government has adopted a noise-rehabilitation programme, where
currently 100 Mio€ are spent per year for noise reduction measures (mostly noise barriers) according to a priority list.


4. Deutsche Bahn has set itself the ambitious goal of reducing the noise emission by 10 dB(A) by the year 2020 compared to year 2000 [4].

5. The ‘TSI-Noise’ sets limit values for the noise emissions from new rolling stock and also for vehicles undergoing major reconstructions.

This shows clearly that there is a high demand for noise reduction technologies, which can guarantee the required protection level to the residents while safeguarding the competitiveness of rail traffic at the same time. Therefore DB actively supports the development of innovative noise reduction technologies. DB is a major partner in R&D projects both on national and on European level, bringing in the full expertise of its engineering centre DB Systemtechnik. The German Federal Government has launched in 2009 an investment programme for the purpose of stimulating economic activity in response to the financial crisis. A considerable share of the allocated budget (50 Mio€) is provided for implementation and test of innovative noise mitigation solutions at various locations on DB’s infrastructure with the focus being on noise reduction at source.

This paper will give in the first part an overview of innovative noise reduction technologies, which are already in regular use or which are currently being tested by DB. The second part will focus on the issue of vibration mitigation.

2. REDUCTION OF ROLLING NOISE

Numerous sources may contribute to the total noise emission from rail traffic like e.g. noise from engines (diesel/electric), squeal noise from tight curves, and aerodynamic noise at very high train speeds. However, the dominant source in most cases with existing noise problems is rolling noise. Therefore sustainable noise reduction essentially means substantial reduction of rolling noise. Fig. 1 shows the general mechanisms contributing to the generation of rolling noise. Imperfections of the surfaces of rail and wheel (roughness) cause time-dependent contact forces at the rail/wheel contact. These contact forces lead to vibrations of both wheel and rail. Below a certain frequency (depending on the stiffness of the rail fastening system) also the sleeper will be excited.

From Fig. 1 it becomes clear that there are in general three options to reduce rolling noise:

1. Reduction of the roughness of rail and wheel
2. Reduction of the vibration of rail, wheel and sleeper
3. Shielding of the radiated sound waves

DB supports activities in all these three fundamental building blocks of a strategy for sustainable reduction of noise. The following gives a brief overview.

2.1. Specially monitored track and brakes with K-blocks

Over a period of more than 10 years, DB has developed, implemented, and continuously improved a system called ‘Specially Monitored Track’ (in German: ‘Besonders Überwachtes Gleis – BÜG’) [5] where a certain standard of rail roughness and a correspondingly low level of rolling noise emission is being guaranteed to the residents living close to a railway line. BÜG essentially consists of two components:

1. Half-annual surveillance of noise emission by the monitoring car of DB Systemtechnik.
2. Acoustic rail grinding when the monitoring car indicates the exceeding of a certain threshold value.

This ensures that the average noise emission of a BÜG-section is 3 dB(A) below the average value of a track without any special treatment for acoustical purposes. At present more than 700 km of DB’s network are defined as BÜG.

The optimum effect of rail grinding is obtained only when the wheels of the rolling stock have a roughness lower than the roughness of the rail. While this is generally the case for passenger coaches with disk brakes, freight wagons with cast-iron brakes have very rough running surfaces so that the noise emission from freight trains is almost entirely caused by the wheel roughness. Brake blocks made of composite materials can considerably reduce the roughening of the running surface when the brake is applied. Field tests have shown that rolling noise from freight wagons may be reduced by up to 10 dB (A) [6]. Fig. 2 displays the measured noise level in dB(A) during the pass-by of a freight train, where the front section was composed of freight wagons with composite block brakes (K-blocks), while the rear section contained only wagons with conventional cast-iron brake blocks.

![Fig. 2: Noise level in dB(A) recorded during the pass-by of a freight train where the front section was composed of freight wagons with composite block brakes (K-blocks), while the rear section contained only wagons with conventional cast-iron brake blocks.](image)

Brakes with composite blocks are standard for new rolling stock acquired by DB. At present more than 6000 freight wagons with K-blocks belong to DB’s rolling stock. On the other hand, a sustainable noise reduction from freight traffic requires at least 80 % of the freight wagons to be equipped with K-brakes. This means that, due to the long life-time of freight wagons, there is a high demand for retrofitting the existing fleet. In a pilot project funded by the German Federal Government 1250 freight wagons (mainly in service along the Rhine corridor) will be retrofitted with K- and LL-blocks beginning in 2011.

2.2. Damping of rail and wheel

Rail damping has been shown to increase track decay rates, reducing the distance travelled by the vibration energy and thus reducing the noise generated by the track. Various designs for rail dampers have been developed in the past. Fig. 3 shows two types of rail dampers which are currently being installed at different locations on DB’s network with existing noise problems. Both types consist of steel elements and elastomer-based materials. Hence, they represent damped mass-spring systems,
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absorbing energy through internal friction in the elastomer as the steel elements vibrate in response to vibrations in the rail.

**Fig. 3:** Rail dampers developed by Schrey & Veit (left) and by Tatasteel (right). Both types are being installed on several sections with existing noise problems on DB’s network.

It is a rule of thumb that both rail and wheel emit roughly the same sound energy (in detail this of course depends on the type of rail and wheel and to a large extent also on the train speed). Therefore increasing the damping of the wheels can also considerably reduce the overall noise emission from rail traffic. Wheel dampers made of stacks of metal sheets separated by elastomers is a well-developed technology, which is applied by DB for the wheels of the ICE high speed trains. Their effect at higher speeds ($v > 100 \text{ km/h}$) is of the order of 4 dB(A), which has also been acknowledged by the German noise legislation. Particularly challenging is the goal to considerably further reduce the rolling noise of freight wagons equipped with K-blocks by adding dampers to the wheels. Unlike in the case of disk braked wheels, wheel dampers for tread-braked wheels are not yet commercially available due to the high temperatures the wheel is subjected to during braking. Additionally, dampers for freight wagons have to be a low-cost solution in the sense that their additional costs do not weaken the position of the freight wagon operators in the highly competitive freight market particularly with respect to road traffic.

### 2.3. Innovative noise barriers

The classical noise reduction measure for the transmission path between source and receiver is the noise barrier at a distance of about 4m from the track and with typical height between 2m and 4m. Responding to the growing concern of residents about the negative impact of high noise barriers particularly on cityscape, alternative concepts are under development:

- **Gabion walls:** Baskets made of galvanized wire or metal rods, filled with broken stones. These have the advantage of fitting well into the landscape.
- **Curved transparent noise barriers.** Transparent noise barriers are in general non-absorbing and therefore of limited use for rail traffic as they allow for multiple reflection between noise barrier and the side-walls of the coaches. This problem can be circumvented by designing noise barriers with a special curvature such that the reflected sound waves are focused into the ballast.
- **Low height noise barriers close to the track.**

It is intended to install prototypes for all three approaches in 2011 and to subject them to thorough field testing. This shall not only include the acoustic performance but also safety aspects, impact on track maintenance and general system compatibility.
3. INNOVATION PROJECTS

In order to support the process of technological development in the field of noise and vibration control, DB is a major partner in innovation projects both on national level in Germany and on international level. These innovation projects generally include close cooperation with other European railway companies, with providers of rolling stock, infrastructure components and noise mitigation technology, and with research institutes. While R&D is clearly the responsibility of manufacturers and research institutes, DB Systemtechnik as Europe’s largest centre of excellence for railway technology brings in its competence in order to define the requirements of a railway operator and to ensure the compatibility of technologies with existing standards and regulations. Furthermore, DB provides test facilities, conducts field tests and assesses developments in terms of their performance and their life-cycle costs. The following gives an overview of on-going and recently finished innovation projects with major DB participation.

3.1. SILENCE

SILENCE was an integrated research project funded by the Sixth Framework Programme of the European Commission to develop methodology and technology for improved control of surface transport noise in urban areas including city authorities, individual traffic (on road) and mass transport (on rail and road). The railway-related activities were concentrated on two subprojects led by SNCF (“Railway Vehicles”) and by DB (“Railway Infrastructure”). DB’s major contribution to the project consisted of conducting field tests for dampers of rail and wheel in combination with extensive measurement campaigns.

Particularly challenging was the goal of considerably further reducing the rolling noise of freight wagons equipped with K-blocks (which within SILENCE was considered to be state of the art) by adding dampers to the wheels. Prototypes of the wheel dampers developed by Lucchini S.A. (see Fig. 4-left) were tested by DB Systemtechnik in a measuring 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 performed on rails with and without rail dampers. Fig. 4 (right) shows a summary of the measured noise reduction obtained with rail dampers, wheel dampers and a combination of both.

![Fig. 4: Left: Hypno wheel dampers developed by Lucchini S.A. within SILENCE. Right: Measured noise reduction in dB(A) obtained with rail dampers (left column), wheel dampers (right column) and the combination of both (middle column).](image)

3.2. LZarG (‘Leiser Zug auf realem Gleis’)

To further reduce railway noise DB started a national research and technical development project in which both academic and industrial partners are involved. Within the projects duration 2007 to 2010 economically satisfying solutions are to be developed which will act in addition to the K-block technology. The project focuses on the different noise emitting components and their interdependencies. The project comprises the optimization of wheels, bogies and the track system [7]. One subproject covers the wheel/rail contact in detail with the aim of optimizing the bogies of freight
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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 effected by developing a new wheel shape design as well as wheel dampers within a second subproject. This includes extensive laboratory tests on DB Systemtechnik's roller test rig at it's Brandenburg/Kirchmöser. Also the disks of the braking system connected to the wheelset in the case of regional trains are taken into account. A third subproject covers the acoustic optimization of the track system. This is to include damping devices mounted to the rail, and under sleeper pads. The rail dampers developed by Vossloh have already been mounted to the rail with hard rail pads near Augsburg (see Fig. 5). First acoustic measurements show a damping effect of 1-2 dB(A) depending on train categories.

![Fig. 5: Rail dampers mounted on an existing track near Augsburg](image)

These three subprojects are combined in the part ‘reduction of rolling noise’ and cover the technical aspects of the project. In the final phase of the project all improvements achieved are currently being evaluated in field tests with a test train on different track systems.

3.3. STARDAMP

STARDAMP (‘Standardization of damping technologies for rail and wheel’) is a French-German collaborative project bringing together the major stakeholders in the field of damping technologies in order to reduce railway noise (manufacturers, railway operators, research institutes). DB Systemtechnik is in charge of coordinating the German part of the project and SNCF of coordinating the French part. The aim is to develop a generally agreed methodology for the assessment of damping technologies for rail and wheel, avoiding costly and time consuming field tests as far as possible. The STARDAMP results shall bridge the gap between the R&D phase and regular application and, hence, reduce costs and considerably shorten the innovation cycles. Measurement protocols will be worked out for physical quantities, which determine the performance of a rail or wheel damper and which can be measured in the laboratory (e.g. track decay rates). A software tool will be developed and validated, which uses these quantities as input and assesses a damper in terms of noise reduction. ‘Non-acoustic’ quantities relevant for the assessment of a damping technology (safety, LCC etc.) will be specified. Guidelines for the application of the full methodology by the targeted group of end users will be worked out. These will include also an assessment of existing damping techniques for rail and wheel on the basis of the STARDAMP methodology. STARDAMP was launched in October 2010 with the partners DB, SNCF, Vibratec, TU Berlin, Schrey & Veit, Tatasteel, ATSA, GHH Radsatz, Valdunes and is planned for the duration of 2 years.

3.4. LäGiV

In January 2011 the project LäGiV (roughly translated “noise reduced freight traffic due to innovative composite brake blocks”) was launched, partly funded by the German ministry of economics. Under the project leadership of the DB environmental department five manufacturers of composite brake blocks (Becorit, Bremskerl, Federal Mogul, Honeywell and TMD) will start the developing process for a second generation of K- or LL-blocks especially in the direction of optimized life cycle costs. DB Systemtechnik will take the important role to perform all necessary tests (on test benches and on tracks) and will provide the technical coordination for the whole project in order to realise a reduction in developing time for the products.
4. VIBRATION CONTROL

Although noise has received this increased attention in terms of research and implementation of mitigation technology, the related issue of ground vibration has not because noise was more important in the perception. Nevertheless public sensitivity to vibration issues has also increased in recent years. Most complaints of high levels of vibration addressed to mainline railways concern freight traffic on surface lines. This is a significant hindrance to the upgrading of lines for them to become part of a European Freight Corridor. In the case of new lines, vibration mitigation already features heavily in the cost of making them acceptable to the public. Opposition to new lines is as much about the effects of vibration as any other topic, including noise. While noise is an issue for all modes of transport, vibration is specific to rail and therefore stands out all the more as a criticism of rail transport.

4.1. RIVAS

A key element in the R&D activities for efficient vibration mitigation is the RIVAS project (Railway Induced Vibration Abatement Solutions), which is a European project funded within the 7. European Research Framework Program. The RIVAS consortium comprises 26 partners (railway operators, infrastructure manager, manufacturers of rolling stock and track components, construction companies, universities and research institutes) from 9 different European countries. It started in January 2011 and is planned for the duration of 3 years. RIVAS’ mission is to reduce the environmental impact of ground-borne vibration while safeguarding the commercial competitiveness of the railway sector. For many problem areas vibration should be reducible to near or even below the threshold of perception. The project’s goal is therefore to provide the tools to solve vibration problems for surface lines by 2013. It therefore aims to contribute to relevant and world leading technologies for efficient control of people’s exposure to vibration and vibration-induced noise caused by rail traffic. These technologies will be applied to vibration ‘control at source’ (improved maintenance of track and wheel as well as rolling stock and track) and this scope covers propagation measures close to the track as being still within the railway infrastructure. RIVAS will also include effects at the receiver location (i.e. annoyance and exposure of residents to vibrations).

Efficient vibration mitigation requires:

1. a toolbox of efficient vibration reduction technologies (rolling stock/track/transmission) for a wide variety of applications
2. clear procedures for the assessment of the effect of vibration reduction technologies both in terms of physical parameters and human perception

This enables and simplifies the optimum choice of mitigation measures and therefore considerably decreases costs for railway infrastructure and increases the benefits for residents. RIVAS reflects this by combining technical innovation with the development of unified measurement and assessment procedures.

Its main objectives are therefore

- the development of technologies to reduce vibration at source. The focus will be on measures that can be implemented on existing lines (retrofit). They will be applicable to rail vehicle design, rolling stock maintenance, track design, track maintenance, sub-grade engineering, the transmission path within the railway infrastructure
- the development of cost effective test procedures including a measurement protocol to monitor and control the performance of vibration reduction measures, hence making results comparable throughout Europe
- a ‘technology assessment’ in terms of cost-effectiveness, safety issues, operation, potential impact on rolling noise emission, social aspects.

It is an intrinsic part of RIVAS’ strategy that the activities will be driven by end user organisations to ensure that the main objective of developing practice-oriented solutions remains in focus and that the project results will meet the specific requirements of the end users.

4.2. DB handbook 80025 “Ground-borne vibrations”

Germany’s national legislation expressly mentions vibrations as potentially annoying or harmful. As a consequence, vibration emissions have to be predicted in the planning process when building new
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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 planned.

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 [8]. It describes general principles, measurements and prediction, evaluation of ground-borne vibrations caused by rail traffic, mitigation measures and vibrations in connection with construction work. For the prediction of vibrations, the guideline describes a procedure 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: the source system (origin of the dynamic excitation from the concurrence of vehicle and track), the transmission system (propagation of vibration through the soil towards the building) and the reception system (the transfer function describes for example foundation vibrations and the secondary air-borne noise by vibrations of the walls and ceilings inside the building).

Based on vibration-velocity spectra (determined in the way described above), KB values have to be calculated. KB is the frequency-weighted dimensionless vibration-velocity (a definition is found e.g. in [9]). KB is used in several European countries for the assessment of vibrations. In the past, DB implemented several annoyance studies to find characteristic values which describe the human perception of vibrations [10].

5. CONCLUSION

DB is taking its responsibilities for sustainable noise and vibration control 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. This target can only be achieved by the combination of the most efficient noise abatement techniques. The three building blocks of DB’s strategy and their contribution to the overall target are displayed in Fig. 6.

Fig. 6: The three building elements in DB’s strategy to reduce railway noise by at least 10 dB(A) by 2020 compared to 2000

While the standard solution in the past was building noise barriers, the focus now is shifting more towards noise control at source. This highlights the importance for practice oriented innovative solutions, which besides the acoustic performance fulfill the general requirements with respect to safety and system compatibility and which do not negatively affect the competitiveness of rail traffic.

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