NOTES ON NUMERICAL FLUID MECHANICS AND MULTIDISCIPLINARY DESIGN · VOLUME 118

Noise and Vibration Mitigation for Rail Transportation Systems

Proceedings of the 10th International Workshop on Railway Noise, Nagahama, Japan, 18–22, October 2010

Tatsuo Maeda • Pierre-Etienne Gautier
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Springer

118 Notes on Numerical Fluid Mechanics and Multidisciplinary Design (NNFM)

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ISBN 978-4-431-53926-1 e-ISBN 978-4-431-53927-8

DOI 10.1007/978-4-431-53927-8

Notes on Numerical Fluid Mechanics and Multidisciplinary Design ISSN 1612-2909

Typeset & Cover Design: Scientific Publishing Services Pvt. Ltd., Chennai, India.

Printed on acid-free paper

5 4 3 2 1 0

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NNFM Editor Addresses

Preface

This book contains the presentations given during the 10th International Workshop on Railway Noise (IWRN10), which took place in Nagahama, Japan, October 18–22, 2010. This was the first time that the event had been staged in Asia. The workshop was organized by the Railway Technical Research Institute, Japan (RTRI), and was supported by the Ministry of Land, Infrastructure, Transport and Tourism and the Ministry of the Environment, Japan.

In total, there were 146 participants from 15 countries across the world: 73 from Japan, 11 from the United Kingdom, 11 from China, 11 from Sweden, 7 from Germany, 7 from Australia, 6 from France, 5 from the United States, 5 from Korea, 3 from Belgium, 2 from the Netherlands, 2 from Denmark, 1 from Austria, 1 from Singapore, and 1 from Spain.

IWRN10 covered not only railway noise but also other environmental problems such as vibrations and micro-pressure waves from tunnel portals. Sessions were classified into 7 categories: 1. Prospects, legal regulation, and perception; 2. Wheel and rail noise; 3. Structure-borne noise and squeal noise; 4. Ground-borne vibration; 5. High-speed trains (aerodynamic noise and micro-pressure waves from tunnel portals); 6. Interior noise and sound barriers; and 7. Prediction, measurements, and monitoring. As many as 50 papers were presented in oral sessions and 20 papers were given in poster sessions.

Papers submitted to IWRN10 from many countries showed that the understanding of environmental phenomena and their countermeasures are essential if railway networks are to prosper and high-speed railways are to be developed around the world. IWRN10 presented state-of-the-art technology on environmental phenomena and their countermeasures and demonstrated aspects, theoretical models, and prediction tools on wheel and rail noise, squeal noise, structure-borne noise, aerodynamic noise, micro-pressure waves from tunnel portals, interior noise, and ground-borne vibrations.

Following the tradition of the previous workshops, IWRN10 was held as a single-session event for participants to exchange information on all facets of railway environmental problems.

The International Committee of IWRN supports the chairman of IWRN10 during the preparation process with the experience and expertise of its members. Assistance is given to formulate the scientific program, to release the Call for Papers, to perform the paper selection process, to act as session chairmen at IWRN10, and to act as a peer review group for the IWRN10 proceedings.

Special thanks are due to Masao Uchida, Koichi Goto, and other members of the planning committee and the executive committee of RTRI for all the hard work and care in organizing the conference.

The editors are grateful to Prof. E.H. Hirschel as the general editor of the “Notes on Numerical Fluid Mechanics and Multidisciplinary Design” and also to the staff of Springer Japan for the opportunity to publish the proceedings of IWRN10 in the series.

We look forward to this volume being used as a “state-of-the-art” reference by scientists and engineers involved in solving environmental problems of railways.

November 2010

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Transportation Noise Annoyance, Cognitive Performance and Sleep Disturbances Related to Temporal Structures and Traffic Modes (Deufrako Project "RAPS")

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Summary

The aim of this project is to further understand the influence of transport noise on sleep, to apply this knowledge to the development of measures for the reduction in noise. The topic comes within the scope of a DEUFRAKO cooperation (Noise group) and is subsidised by the ADEME, for the French part of the program. The project brings together some major French and German specialists in this field; the SNCF and DB have contributed to the development of scenarios that are the most representative of the current situation. The French part of this project has now been completed, and is presented in this paper. Two subjects were studied. On one hand, the LINC concentrated on sleep studies. The analysis of train noise influence on the sleeping pattern and the cognitive performances, as well as its impact on the cardiovascular system carried out by the LINC is developed in this paper. On the other hand, tests on cognitive performances and short-term discomfort have been carried out by the LMRTE. The experiments linked to the sound quality of the pass-by as well as the results related to the study of the influence of temporal parameters on functional discomfort are presented. The results concerning railway noise will be compared with road and aircraft noise at the end of the project in partnership with the German part.

1 Introduction

The noise generated by road and aircraft is the main source of noise pollution mentioned by the populations surveyed. However, in the context of policies of local and state authorities regarding growth of sustainable development, the train, which is not very polluting, and is expected to be the major means of transport in

T. Maeda et al. (Eds.): Noise and Vibration Mitigation for Rail Trans. Sys., NNFM 118, pp. 1–8.
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the future. Moreover, railway traffic is predicted to grow in the coming years. To avert the inconvenience and noise annoyance caused by more railway traffic or the construction of new lines, new studies have been planned.

The Project RAPS aims at the provision of applicable knowledge that allows the directed development of noise abatement measures. Within the framework of a Deufrako (Noise group) co-operation, this project brings together some major specialists. The French partners involved are SNCF, LINC and LMRTE, with French funding by ADEME. The German partners involved are DB, CUE, DLR and IfADO.

ADEME :	*Agence de l'Environnement et de la Maîtrise de l'Energie*
CUE :	*Catholic University Eichstätt-Ingolstadt*
DB :	*Deutsche Bahn*
DLR :	*Deutsches Zentrum für Luft und Raumfarhrt*
IfADO :	*Leibniz Research Centre for Working Environment and Human Factors at TU Dortmund*
LINC :	*Laboratoire d'imagerie et de neurosciences cognitives*
LMRTE :	*Laboratoire Mobilités Réseaux Territoires et Environnement*
SNCF :	*Société Nationale des Chemins de fer Français*

This project concerns

1) the quantitative difference of sleep disturbances resulting from noise emitted by rail, road and air traffic,
2) the significance of temporal structure of railway noise on annoyance, activity interference and sleep to determine if human beings react generally more to fluctuations than to steady states.

The project focuses on noise emitted from currently operating trains, while including possible future technical advances.

Until now, studies have been carried out concerning the noise of aircraft and road traffic in relation to sleep disturbance, but not much research has been related to railway noise. A previous study with unrealistic noise scenarios led to the result that the railway noise is more disturbing than street traffic. These noise scenarios used nearly the same number of trains, cars and airplanes. In reality, the number of cars is much more than one hundred times greater than the number of trains for the same noise level averaged over a time period.

Realistic noise scenarios were used for sleep laboratory studies at IfADO with real measured train pass-byes during a night period at different sections of the DB network; and for sleep laboratory studies at LINC with real measured train pass-byes of the SNCF network.

The project started in April 2006 on the French side and in January 2007 on the German side.

Here, the French contribution to the study is presented in two parts. In the first part, tests on cognitive performances and short-term discomfort have been carried out by the LMRTE. The experiments linked to the sound quality of the pass-by as well as the results dedicated to the study of the influence of temporal parameters on functional discomfort are presented. In the second part, the LINC concentrated on sleep studies. The analysis of train noise on the sleeping pattern and the cognitive performances, as well as their impact on the cardiovascular system carried out by the LINC is discussed here.

2 Influence of the Temporal Structure of Railway Traffic on Sound Quality and Functional Discomfort

2.1 Sound Quality of the Pass-By

LMRTEs objective was to characterize the perception of the passage of various types of trains with particular attention paid to the temporal dimensions. The sound quality of the pass-by was studied to identify which information was perceived and to what extent it had an influence on the choices of subjects.

Methodology: A collection of 24 stimuli of equal length and each containing only a single passage was built. During the recording of the signals, two variable parameters were retained: the type of train (Corail, Freight, TER, TGV) and the measurement distance from the track (7,5m, 50m and 100m), the spectral and temporal properties being different according to these two parameters. The signals were recorded in free field. The speed of the pass-by was constant and dependent on the type of train (Corail/TGV: 160kph; Freight: 100kph; TER: 140kph). The sites were selected to minimize the environmental effects (ground effect etc.).

Because the level is strongly related to the annoyance [Fastl: 90], the 12 stimuli were standardized in relation to level L_{Aeq}. A low variation of level was then introduced to compare the influence of a given level to those of other perceptive effects. New versions of the standardized recordings were created by increasing the mean level by 2 dB, before being included in the collection.

The stimuli evaluation was carried out with a perceptive test on the comparison method by pairs used in numerous studies (see for example [Parizet: 05]): the subjects had to estimate the dissimilarity between the signals, indicate their preference and explain their choice verbally.

For each test, only part of the complete collection was used. Four sub-groups were dedicated to a single category of train for the three measuring distances. The fifth sub-group made the crossed study possible for all the categories at 50m and 100m. The study for the TGV trains is detailed in [CFA2010/66].

Conclusions: The analysis of the results (INDSCAL, correlation, linguistic study, preference scale, etc.) showed the following: (1) the most important perceptive dimension is related to the fluctuations resulting from the passage of different wagons. It explains the differences heard between the sounds recorded at 7,50 m and the others. (2) The variations in noise level are well perceived (even if strong fluctuations can make them less evident) 5 but do not mask the other temporal or spectral effects. (3) There might be confusion between the variations of level and the temporal variations (length of passage, suddenness of the arrival) or spectral variations, the subjects being able to assimilate both of them. (4) No consensus appears on the question of determining if the length is preferred to the suddenness (and vice-versa). Some subjects qualify a passage as "*rapid*" (positive adjective) when others define it as "*brutal*" (negative). Likewise, some will focus on the "*progressive*" (positive adjective) aspect when others on the "*slow*" (negative) aspect. (5) The noise disruption study shows the spectral aspect remains secondary in relation to the noise level or the temporal aspects.

2.2 Impact of the Temporal Effects on Functional Discomfort

In a second stage, the impact of the repetitions of train pass-by on the functional discomfort in the evening with windows half-open was studied.

Methodology: To be in a realistic noise context, each hour-long scenario is made up of continuous road background noise and various train pass-bys (derived from recordings used for the noise quality tests). The subjects are then in a multi-exposure situation. For the construction of these scenarios, three variable parameters were selected: the number of pass-by, the distance and the state of dominance. For the same reasons as before, the scenarios were standardized in relation to level L_{Aeq}.

A study on the evening French railway traffic gives the average number of pass-by for each category of train over the 18.00 - 22.00 period [Cremezy: 07]. On this basis, two traffic densities were selected for one hour duration: 10 events per hour (6 Corail + 2 Freight + 1 TER + 1 TGV) and 20 events per hour (12 Corail + 4 Freight + 2 TER + 2 TGV).

The recordings at 7.5m had differenct characteristics from the other distances (see section 3.1). Consequently only the pass-bys captured at 50m and 100m were kept: the effect of the suddenness of the arrival can be perceived, whereas the fluctuations due to the pass-by of the wagons are less. The distance will also influence the length of the passage and the distribution of the energy in frequency.

As the "perturbing" aspect of the pass-by can be correlated with the discomfort [Beaumont: 05], the emergence of the pass-by in relation to the background noise was included as a third variable parameter. The dominance of the railway traffic in relation to the road traffic [Champelovier: 03] was therefore considered account. In a dominance situation, we then obtain: L_{Aeq}Trains = L_{Aeq}Background noise + 6dB(A) ; in a non-dominance situation: L_{Aeq}Trains = L_{Aeq} Background noise + 3dB(A).

During the tests, the subjects were placed in a rest situation and invited to carry out a reading activity in a pseudo-anechoic room. At the end of the session, the participants had to evaluate the discomfort, due to the noise environment, to do their reading. This evaluation was carried out according to two scales: a relative scale of evaluation of importance ("To what extent were you disturbed by the noise environment? Twice as much? Three times as much? Etc.") and an absolute scale of categories from 0 (not disturbed at all) to 50 (extremely disturbed). Only the scale of the categories alone made it possible to obtain significant results for the 8 sequences elaborated.

Conclusions: The distribution of the answers, as well as the analyses of variances were carried out to study the subjects' answers. It appears thus that (1) the more pass-bys there are, the less the subjects are disturbed. This can be explained by the fact that the overall level being maintained constant, the peak level values are lower when the traffic is heavier. (2) The non-dominance situations are preferred in general. The subjects reject the trains when they become perturbing elements of the "background" noise. (3) There is an interaction between the dominance and the other variables. The subjects will then adopt distinct strategies as a function of this.

In a dominance situation, the sudden and distinct aspect of the passage will involve an increase in discomfort despite a reduced length of passage. Thus, at a constant overall level, the nearer the participants are to the tracks, the more they are disturbed. In a non-dominance situation, the lengths of the pass-by will influence the discomfort: the emergence being reduced, the trains are more easily associated with the background noise. This noise will thus become more perturbing and the discomfort will increase with the distance from the tracks (at constant overall level).

The suddenness/length opposition appears once more. We rediscover here the various listening strategies already observed during the noise quality evaluation (section 3.1). Some subjects focus their attention on the suddenness of the arrival, whereas others focus on the length of the passage. Putting them in a noise situation with several listening contexts makes it possible to understand better on which temporal aspect(s) the participants base their evaluation of their level of functional discomfort.

2.3 Discussion

In this study, the use of recorded stimuli in situ involves a limitation directly due to the natural correlation between the various characteristics of the signals (distance in relation to the tracks, suddenness of the arrival, length of the passage, spectra etc.). It would be interesting to pursue this work using synthesis stimuli. The various properties could be decorrelated and their impact evaluated independently. We could then associate one single perceptive aspect to one single acoustic magnitude.

During this study, we were confronted by the lack of pertinence of some psychoacoustic tools as regards the characterization of temporally variable phenomena. It is, therefore, necessary to persevere in the development of tools aimed at the characterization of these phenomena to define, for example, a robust and representative indicator of the rhythm associated with the passage of the wagons.

Lastly, to increase the statistical significance of the study, it would be advisable to build tests where each subject would listen to all the noise sequences. We would thus limit the inter-individual variability, but we would also introduce an habituation effect to the test. Moreover, it would be possible to measure the effect of the noise environment on the performance, not in terms of the number of correct responses (which seems to be independent from the noise load), but in terms of response time (or reading time). In fact, a slowing down could appear under the effect of the pass-by, as suggested by some subjects ("The passage of the train stopped my reading and distracted me; "The ear is attracted by the train noise and therefore concentration is impaired", etc.).

3 Sleep Disruption Linked to Transport Noise

In general, this last section carried out by the LINC demonstrated that night train noise administrated sporadically have not much effect on the sleeping pattern and the cognitive performances the next day, but that permanent exposure to night train noise produces adverse effects on the cognitive performances.

3.1 Material and Methods

The study involved two groups of 20 subjects (men and women) divided into age groups: a group of young subjects (age 20-30: 26.2 years ± 3.6 years) called the Junior Group, and a group of middle-aged subjects (age 45-60: 56.2 years ± 4.2 years) called the Senior Group. Each of these groups was in turn divided into two sub-groups, living either near a railway line (noisy environment) or in a quiet area (quiet environment). The recruitment of the subjects in a noisy area was done due to the SNCF selecting portions of line with an average night railway traffic of 25 to 30 freight trains per night.

The study was carried out in two stages: a study on site, including three consecutive nights of actigraphic recording (and subjective questionnaires: discomfort related to noise pollution, subjective perception and somnolence, …), and a laboratory study consisting of four non-consecutive nights spaced out by about one week each (habituation night, control night, low density night (30 trains/night), high density night (60 trains/night)). The laboratory nights were all followed by a whole day dedicated to the iterative realization of various cognitive tasks with subjective measurements. The same subjects took part in both stages of this study.

Electrophysiological recordings were carried out during the experimental nights (EEG, EOG, EMG, ECG). In addition, then each session of cognitive performance tests included, in addition to the subjective questionnaires (already used in the first phase at home), three very attentional tasks, very sensitive to effects of sleep deprivation, even partial:

- ANT (Attentional Network task) (Fan et al., 2002)
- PVT (Psychomotor Vigilance Task) (Dinges and Powell, 1985)

3.2 Results Analysis

The night train noise produces an increase in arousal and partial arousal proportional to the density of traffic. The subjects describe an impression of having slept badly which translates from the subjective point of view into an increase in complaints about stress and a bad night. It is essentially from the cardiovascular point of view that the effects of noise pollution are felt, with, in particular, an increase in the cardiovascular response percentage and the amplitude of these responses. Nonetheless, it would seem that the important factor is not so much the density of the traffic, and therefore the frequency of train pass-by, but the noise intensity of the trains as is proven by the more adverse effect of the low traffic night (but with a higher noise intensity per train) in comparison to the high traffic night.

This study also showed that age itself translated, as many other studies have demonstrated, into a deterioration in the sleep quality with in particular a lighter sleep pattern marked by an increase in the lightest stages and a diminution of the slow and deep sleep stages, an increase in its fragmentation and its instability in terms of the number of stage changes. On the other hand, contrary to the majority of studies, the cognitive performances the next day were not very poor for the seniors. However, this could be the result, not of better performances in this senior group in particular, but worse performances by the young subjects. In fact, the objective evaluation of the daytime sleep pressure by the wakefulness EEG clearly demonstrated that the young subjects presented higher spectral densities than the seniors, which translates into a higher somnolence, and, therefore, a higher sensitivity of the young subjects to night noise pollution.

However, the most striking result of this study arises from the difference observed between the subjects living near a railway line in comparison to those living in a quiet area. It appears that these subjects, irrespective of their age, present in general, poor performances essentially at the level of reaction times and, therefore, the rapidity of information processing.

This could be the sign of a chronic lack of sleep. However, the examination of their sleeping pattern clearly reveals that when they are laboratory evaluated, the subjects normally living near a railway line have a deeper sleep than those living in a quiet area, which probably translates into a phenomenon of compensation linked to the lack of sleep associated with a behavioural habituation to the noise translating into a form of desensitizing.

Furthermore, these subjects also differ on the cardiovascular level. The cardiovascular reactivity is very clearly reduced in seniors living in a noisy area in comparison to seniors living in a quiet area. On the contrary, among the juniors, those living in a noisy area present a cardiovascular reactivity much higher than those living in a quiet area. Therefore, everything happens as if, in the short term, the chronic exposure to noise produces a hypersensitivity of the vegetative system to noise, whereas with time, and contrary to what was suggested by previous studies, we notice an habituation translating into an extremely reduced reactivity. In fact, even if it is a known fact that the cardiovascular reactivity is considerably reduced with age, probably due to the ageing of the arteries, this would not explain why there is such an obvious difference between the two groups of seniors.

4 Conclusion

The LMRTE studied the sound quality of the train pass-by and their influence on functional discomfort. Their work, within a post-project perspective, would need to be improved, in particular by decorrelating the signal characteristics (use of synthesised signals). The LINC, for its part, analyzed the effect of night train noise on sleeping pattern and cognitive performances. They demonstrated that when they are administered sporadically, they have not much effect on the sleeping pattern and the cognitive performances the next day, as well as their repercussions on the cardiovascular sphere. The SNCF supplied traffic data to define the most representative scenarios of real current and future situations (traffic doubled), brought its railway expertise in the implementation of methodologies and contributed to discussions on the results analysis.

In general, the study made it possible to demonstrate that train noises, while being generally considered as harmless or relatively ecological, present nonetheless all the effects that will have to be taken into consideration if we want to develop railway freight further.

The exchanges with the German part will be presented later and complete and enhance the analyses and conclusions presented here. In fact, the work carried out by the French part only concerns the railway transport mode, contrasting a quiet environment to an environment beside a railway line. The German laboratories have also been worked on all the transport noise: road, aircraft and railway noise. Their work makes it possible to compare and takes into perspective the relative effects of each mode of transport.

Acknowlegments

This project comes within the scope of a DEUFRAKO cooperation (Noise Group) and is subsidised by the ADEME, for the French part.

We would like to thank in particular, all the partners involved in the project [CFA2010/525], and the persons who took part in the experiments and made the realization of these studies possible.

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Advancements in Noise and Vibration Abatement to Support the Noise Reduction Strategy of Deutsche Bahn

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Summary

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 strategy. DB has set itself the goal of halving, by the year 2020, the level of rail traffic noise experienced by local residents in 2000.

1 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" 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 lay down action plans to prevent and reduce environmental noise based on the noise-mapping results. Cost-effectiveness will play a crucial role in the noise reduction strategies.

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 [3]. If this target of 10 dB(A) reduction in the residents noise perception is to be achieved, all available and new abatement techniques need to be used.

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2 Noise Reduction Strategy of DB

DB is implementing the voluntary noise rehabilitation programme of the German government. With the introduction of this scheme, it became possible to implement noise protection measures along existing sections of railway tracks. Meanwhile 100 Million € have been made available annually for this programme to install noise protection walls or sound proofed 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 [4].

Major reductions in noise emission levels of freight wagons are now feasible. The novel composite brake block (known as the "K-block"), which has undergone extensive testing, was recently approved for international use [5]. Up till 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. For mixed freight and passenger traffic conditions, the overall effect is 4 to 5 dB(A) noise reduction.

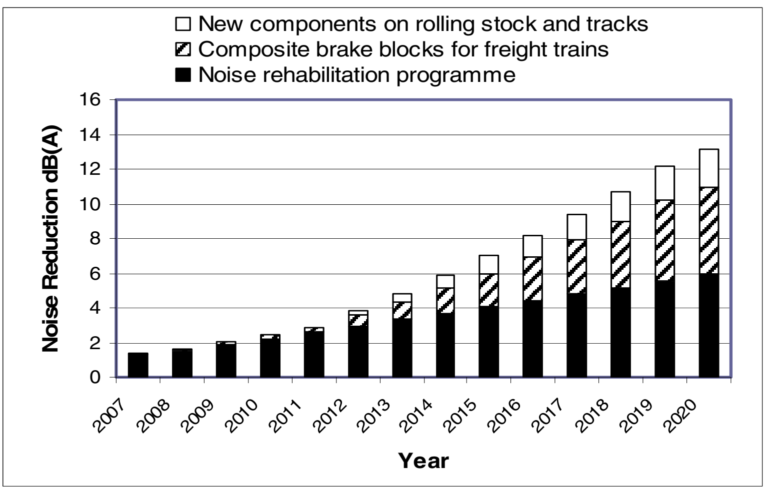

Fig. 1. The three building elements in DB's strategy to reduce railway noise by at least 10 dB(A) by 2020 compared to 2000

To achieve the goal of at least 10 dB(A) noise reduction all over the country, up to 5 dB(A) diminution is necessary in addition. Therefore, the third important building element in DBs national plan to reduce railway noise by at least 10 dB(A) by 2020 is the development of new noise-reducing components for rolling stock and track. The outcome of these efforts will add notably to the effect of the federal noise rehabilitation programme and to noise reduction by retrofitting composite brake-blocks to freight wagons. Fig. 1 shows how the three elements add up to achieve the goal.

3 Development of New Noise-Reducing Components for Rolling Stock and Track

3.1 EU Project SILENCE

Substantial strategies and measures for noise reduction options were under development within the SILENCE project [6], where Deutsche Bahn was involved as a major partner during the project's duration from 2005 to 2008.

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. "Integrated" means the combined consideration of city authorities, individual traffic (on road) and mass transport (on rail and road). Within SILENCE, 15 partners from railway undertakings (Trenitalia, STIB, SNCF, DB), the railway industry (ALSTOM, Ansaldobreda, Bombardier, CRF, Lucchini S.A, Corus, D2S), as well as engineering and academic institutions (ISVR, KTH, VTC, Deltarail) formed a railway-related sub-consortium. The railway-related activities were concentrated on two subprojects led by SNCF ("Railway Vehicles") and by DB ("Railway Infrastructure"), the latter focusing on the development and implementation of efficient infrastructure-based noise reduction technologies. DBs major contribution to the project consisted of conducting field tests in combination with extensive measuring 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 in the intensity of the radiated sound field by increasing the damping of the rail and wheel. The second option was followed within SILENCE. The goal of considerably further reduce 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 was particularly challenging. Unlike disk-braked wheels, where dampers are known to be an efficient way to reduce noise emission by about 4 dB(A), wheel dampers for tread-braked wheels are not yet commercially available due to the high temperatures the wheel is subjected to during braking.

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. The development of the rail dampers was carried out by Corus Rail and was supplemented by extensive modeling and computer simulation performed by the Institute of Sound and Vibration Research at the University of Southampton. Rail dampers with improved acoustic coupling to the rail web were installed on a test track near Augsburg (see Fig. 2). In an extensive measuring 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 observed [7]. The mitigation effect of the dampers depended on the train speed and on track stiffness.

Fig. 2. DBs 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) (color figure online)

Prototypes of the wheel dampers developed by Lucchini S.A. (see Fig. 2) were tested in another measuring campaign in September 2007. A total of 24 wheel dampers were mounted on to the wheels of a test train with sliding wall freight wagons. Their noise emission was measured and compared with that of wheels without dampers. These tests were performed on rails with and without rail dampers. Fig. 3 shows a summary of the measured noise reduction obtained with rail dampers, wheel dampers and a combination of both.

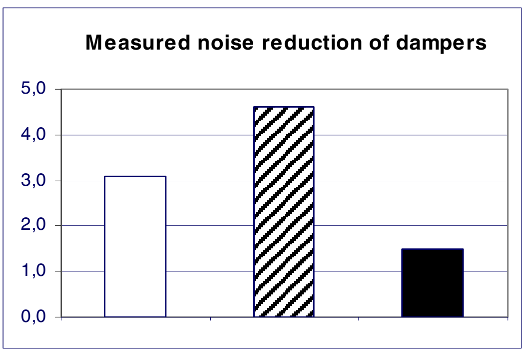

Fig. 3. Measured noise reduction in dB(A) obtained with rail dampers (left column), wheel dampers (right column) and the combination of both (middle column).

3.2 Federal Project "LZarG" - Low-Noise Train on Existing Tracks

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 [8]. One subproject covers the wheel/rail contact in detail with the aim of optimizing the bogies of freight trains 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. In addition, the disks of the braking system connected to the wheelset in the case of regional trains are taken into consideration. A third subproject covers the acoustic optimization of the track system. This is to include damping devices mounted on to the rail, and under sleeper pads. The rail dampers developed by Vossloh have already been mounted on to the rail with hard rail pads near Augsburg (see Fig. 4). First acoustic measurements show a damping effect of 1-2 dB(A) depending on train categories.

Fig. 4. Rail dampers are mounted on an existing track near Augsburg (color figure online)

These three subprojects are combined in the part “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. By an adequate combination of measures on rolling stock and the track system, the noise abatement effect will be maximized (color figure online).

3.3 DB Handbook 80025 “Ground-Borne Vibrations”

During the passage of track-bound vehicles, not only noise, but also vibrations are generated at the wheel—rail contact point, transmitted via track and superstructure into the substructure, transferred through the ground (soil) and can generate noticeable vibrations inside adjacent buildings. 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 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.

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 [9]. It describes general principles and fundamentals, measurements and prediction, evaluation of ground-borne vibrations caused by rail traffic, mitigation measures and 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: the source system (origin of the dynamic excitation from the concurrence of vehicle and track), the transmission system (propagation of the 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 the 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 e.g. in [10]). KB is used in several European countries for the assessment of vibrations.
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 in describing the disturbance level [11].

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 particular situation depends on the frequency range of the excitation of the main peaks in the KB spectrum. 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 perception 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 great deal in investigations and specific measures in the last few years (e.g. in connection with the new railway tunnel crossing the centre of Berlin [12] 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. 5).

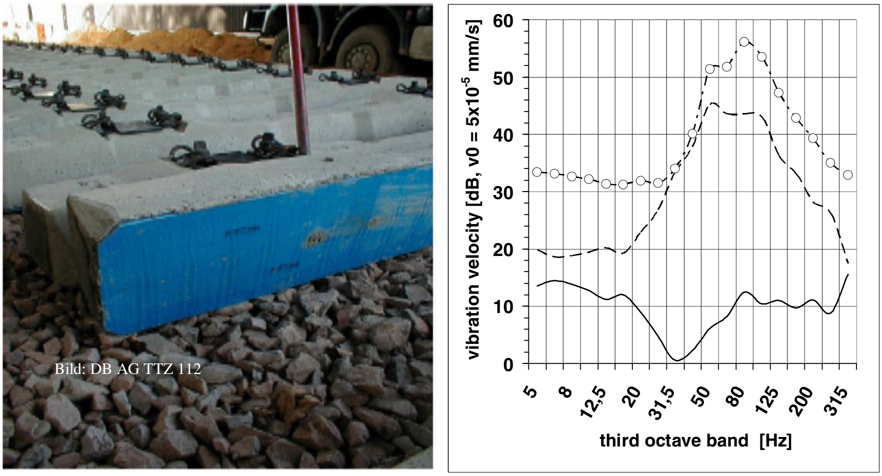

Fig. 5. Retrofit of a tunnel with sleepers with USP and measured vibration level in vertical direction on first floor of an adjacent building before (-0-0-) and after (-----) the installation of under-sleeper pads and the insertion loss as the difference spectrum (______). (color figure online)

DB has been participating in a UIC-funded project (UIC Project No I/05/U/4440 "Under Sleeper Pads") to share information and experience with USPs in different fields of applications. 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 [13] (see Fig. 5). DB has summarized its specifications for USPs in the standard DBS 918 145 [14]. 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 provided a consistent picture yet. Some measurements indicated a negligible effect, while others recorded considerably increased noise emission. Further research is necessary here.

4 Conclusions

This article describes the three building elements of DBs noise reduction strategy to support DBs self-obligation of halving, by 2020, the level of rail traffic noise compared with the amount experienced by local residents in 2000. To achieve this ambitious target, well-coordinated implementation of state-of-the-art noise abatement techniques, as well as new noise reduction techniques covering both vehicles and infrastructure is needed. After completing the projects mentioned, DB will be able to use the end results to halfen the railway noise level. Tools, methodologies and input data for decision support systems are available as well.

Acknowledgements

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.

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