ABSTRACT
The research programme of the Deutsche Bahn AG (DB) is presented which aims for a major leap within the next years towards less railway noise production. In five projects primary noise experience via the ambient air as well as the secondary noise experience via the ground vibrations are tackled from the source to the residents. Beside these investigations, the sound perception and noise assessment is paid attention, too.

1. - INTRODUCTION
In the last few decades, mobility in Europe, based on automobiles for individual traffic and lorries for freight traffic, has grown more and more; yearly growth rates of more than 10% have often been reported by statistics. These growth rates cumulated over the years cannot easily be handled in an environment-friendly way. The European Commission has therefore given distinct political signals to get more passengers and more freight onto the railways. An efficient trans-European transportation network is indispensable to handle this mobility increase.
To empower the environmental friendliness of the railway traffic in Germany [13], the Deutsche Bahn (DB) is in between of absolving a major research programme concerning noise reduction. The final goal of this ambitious research agenda is to achieve a decline in overall noise production by up to 10 dB(A) compared to 1990 by the year 2005 for DB's business units for freight and passenger traffic as well as the infrastructure division.

2. - NOISE REDUCTION RESEARCH AT DB
The representative "acoustical" situation around a train in motion on a railway line is shown in Figure 1. Train and track both act as the sound sources and the two ways of noise transmission make two lines of research indispensable.

Figure1: Acoustical situation around a train in motion on a track section
Since in the air only longitudinal waves are possible, the classical rules of acoustics can be used to trace the sound waves from the source to the railway line residents whom they may disturb (see e.g. [10]). The direct noise experienced by these residents can be reduced both by limiting the strength of the sound source and by extending the transmission path of the sound wave by making use of the screening effect of sound barriers. Also the installation of noise protection windows represents a counter-measure against too high noise exposure.

In the ground, the transmission of energy is possible by longitudinal as well as by transversal waves and different mixed wave structures can be identified apart from these pure wave types. This makes the analysis of the acoustical problem from the source to the residents' ears more complex since transmission of the wave energy through the ground and formation of the secondary sound in the houses involve more parameters and influencing quantities.

To realise this goal, seven projects are running within the DB programme "Low Noise Railway". These deal simultaneously with the noise treatment of the trains and the rail/wheel system and include vibration control, the reduction of noise transmission, the assessment of noise perception as well as the upgrading of the specially monitored track technique (Figure 2). The support of the revision of the two German legislative acoustic-guidelines SCHALL03 for regular passenger and freight traffic along with AKUSTIK04 for shunting yards and transhipment terminals complete the efforts. External scientific institutions, engineering experts and manufacturers are involved in all of the projects in order to obtain a broad view of the problems stated.

All these projects are supervised on a regular basis by associated steering committees with members of the DB’s business areas. They support both the project leader during the work progress and the integration of the results into the daily business as early as possible.

Figure 2: Noise Research Programme of Deutsche Bahn AG (DB)

Thus all impacts of rail-bound vehicle noise, from the sources of noise to the residents near the railway line, are being tackled. Overall expenditure per year is approximately 2.5 million Euro which shows the high priority of these noise reduction activities.
2.1 - NOISE EMISSION OF TRAINS AND WHEEL/TRACK SYSTEM

Since the minimisation of sound radiation directly at the source is the first-choice solution, several work packages deal with the noise emission of the trains and the wheel/track system.

The necessary understanding of the sound sources of high-speed trains was gained within the French-German DEUFRACKO framework in the project K2 "Noise sources from High-Speed guided Transport" [8]. Combined with the DB work in the acoustical analysis of freight traffic in the EU-funded projects SILENT FREIGHT / SILENT TRACK, see e.g. [11], the basis was found for the progressive achievement of low-noise traffic in Europe. Currently the work for the EU-funded project HARMONOISE and the “Leiser Verkehr”, funded by the German government, is performed.

Railway coaches and wagons are equipped with up to 8 wheels and the discs and rims of these wheels are excited by wheel/rail interaction and dominate overall sound radiation. Since this high "loudspeaker" area per unit train length cannot be reduced e.g. because of axle load limitations in freight traffic, silent railway wheels - both for block and disk brake operation - will play an important role in the future to meet the goal of a low-noise railway system.

The basic studies concerning the optimum shape with respect to the acoustic requirements have already been performed (Figure 3), see e.g. [4], [14]. A wheel manufacturer as well as wheel and brake engineers are involved in the workgroup to clarify the questions of the casting process and of the brake and running safety. The full scale investigations will start in brake test bench in autumn 2001 and will be finalised in 2002 with an in-situ test under real operational conditions.

Figure 3: Numerical simulation of the sound radiation of railway wheels with different shapes

Within this project, the development of DB’s microphone array to be equipped with up to 96 microphones was done and first measurements were performed. The array characteristics, resolution and signal-to-noise ratio were evaluated by numerical simulations [16], [17]. Then, array measurements were used to separate wheel and rail noise from a high-speed train. With this array, DB is now able to localise the dominant noise sources in the relevant frequency bands [6], [20].

Figure 4: Noise source localisation of microphone-array measurements
Special attention will be paid in the future to the noise radiation from the pantographs on the engine roofs, as well as to other noise sources which may be located high above the ground, thus being difficult to screen by barriers [1], [2], [3].

2.2 - NOISE PRODUCTION FROM RAILWAY LINE
In the last years, DB has implemented the acoustical concept of the "Specially Monitored Track (SMT)" (in German: "Besonders überwachtes Gleis (BÜG)"). The SMT concept is based on the periodic acoustic monitoring of the relevant track section by means of a test coach specialised for sound measuring. Should noise production be beyond a certain limit, grinding of the track section will remove the tiny periodic rail corrugations which excite the train wheels and lead to sound radiation from the wheels and the rail itself. Figure 5 shows a representative example of the sound pressure level before and after grinding the rails.

Figure 5: Noise emission from railway line before and after local grinding

The Federal Railway Office (EBA) officially confirmed SMT as a noise reduction system with effectively -3 dB(A) for ballasted tracks and slab tracks. Further development of the standard SMT process was done towards a mobile measuring device for rail surface roughness to perform in-situ quality control directly after grinding and towards an application of SMT to slab tracks equipped with a sound absorbing layer.

To complete these activities, an automatic system for sound diagnosis was developed to measure the sound production of the different train fleets at a given track location over a longer time period to gain a better insight into the scatter in the noise emission within a this fleet and its impact on the line emission.

2.3 – UPGRADE OF THE SPECIALLY MONITORED TRACK
The experience of the last years now showed, that the authoritatively stated compatibility conditions for the use of the SMT, i.e.

- periodic acoustic monitoring of the relevant track section by means of a test coach specialised for sound measuring
- monitoring of the grinding quality of the ground track section
- application of the different grinding procedures

need further development and have to be adjusted to the technological progress. DB’s research is therefore marching in two directions simultaneously: to reduce the expenses for this particular reduction rate and to increase for the current cost structure the noise reduction rate.

The typical noise reduction curve over time of the current SMT in Germany is shown in Fig. 6. If a certain track section is subject to the SMT, grinding will immediately decrease the rail noise clearly below 48 dB(A), this value is identical with the so called “base value” in the German legislative framework SCHALL 03. Approximately half a year later the track section
emits an even 1 to 2 dB(A) lower sound pressure level. Afterwards the noise emission increases with time and after around 2 years the so called threshold value of 51 dB(A) is reached, this initiates the next rail grinding. In the current practice the noise emission oscillates over time around the mean value of 48 dB(A) with an amplitude of 3 dB(A).

![Graph: Specially Monitored Track SMT](image)

**Figure 6: Noise reduction grinding as a function of time of the SMT technique using track grinding**

The idea behind the “low-cost” SMT option is now to follow the base value by increasing the frequency of the grinding with a decreased grind-amplitude. The current research is now looking for the cost optimised frequency-amplitude pairing. The “high-performance” SMT option is working with an even higher frequency and smaller amplitude of the grinding in comparison to the low-cost option, but the striking feature is the lower base value. This option aims for a noise reduction rate of effectively –5 dB(A).

Work on rail corrugations which cause rail noise and also excite the wheels is currently focussed on the analysis of the measured data concerning these corrugations and on tracing the growth rate of the corrugations on track sections with different grinding procedures [5].

### 2.4 - NOISE REDUCTION BY MEANS OF SOUND BARRIERS

In relation to rolling noise, the typical screening effect of a 2 m high sound barrier is average 10 dB(A). At up to 1 million EURO/km, the installation of sound barriers is costly and to justify these substantial investment costs the effectiveness of the noise protection installations must be as high as possible. Barriers with 3 or 4 m height will be an exception since they impair the residents. Furthermore, train passengers can no longer enjoy the outside landscape through the coach windows and travelling by train becomes less of a pleasure.

As sound inflection reduces the protection effect of the sound barriers, another means to increasing the effectiveness of the barriers is a better understanding of the inflection properties.
followed by systematic optimisation of the construction of the wall. Since the inflection effect is dominated by the structure of the wall edge, the numerical simulation (Figure 7, see [14]) of several detailed configurations will provide an initial selection of the configurations for later full-scale testing.

The in-situ tests of a “hand-made” prototype showed that the principle of the acoustically soft edges works very well and that the barrier effect can be improved by several dB(A) depending on the distance to the track and the height. Advancement is on going to a prototype ready for an industrial manufacturing process while preserving the acoustic quality.

These investigations are being completed by the quantification of the damping effect of the ground and meteorology in between the sound source and the residents to optimise the overall noise protection. Furthermore the noise damping degree of barriers made of glass are to be investigated, this kind of barriers come into fashion as they are no optical impairment to the residents. These results will also enter the sections related to noise protection in the environmental protection laws in Germany.

2.5 - SOUND PERCEPTION AND NOISE ASSESSMENT

The description of a certain sound experience as annoying "noise" is a very individual judgement and can by no means be considered in terms of physical quantities alone. The question of when sound is qualified as noise is therefore a very basic one and it is investigated parallel to the above-mentioned activities taking physiological and psychological aspects into account.

In several European countries, there is a "bonus" approach towards railway-created noise (Corrective factor rail/road traffic noise). This is based on consideration of the fact that, for a given hourly passing according to sound pressure level, railway noise is to some extent less annoying than noise created by private car and lorry traffic because of the dissimilar sound-production characteristics. The basic investigations were done in the 80s, leading in Germany since 1990 to the permitted “rail bonus” of -5 dB(A) [19]. The same holds for Austria, while, for example, in France it is -3 dB(A) and in Switzerland it is -5 dB(A) to -15 dB(A) depending on the intensity of the rail traffic.

In the meantime the railway traffic situation in Germany changed significantly as e.g. high-speed trains came into operation, existing lines were upgraded for operation up to 200 km/h and the mix of passenger and freight traffic shifted. To reflect these changes and to support the legislative authorities, the assessment of noise quality is re-investigated in detail. The focus is on the comparison of rail and street noise, the perception of high-speed trains noise and the annoyance of conventional passenger and freight train noise. Also the alteration in the degree of annoyance near new built and upgraded railway lines were tackled.
The investigations already finalised show clearly, that the rail bonus is still a valid approach for the annoyance disparity between railway and street traffic and that –5dB(A) are a least gratuity all over the day (Figure 8). A novel outcome was the variation in the annoyance disparity during the day, in the night-time the bonus could be even much higher. Furthermore the high-speed traffic is not more bothering to the residents than standard passenger trains [9], [12], [15], [18].

Figure 8: Compacted result of the noise assessment studies illustrating less annoyance to residents by the rail traffic compared to street traffic

The avoidance of the wheel squeal to be heard from freight wagons on very small-radius track curves is a distinct goal. Up to now, the occurrence of this noise component in freight-train shunting yards could only be reduced by costly sound barriers. To improve this situation, research was performed into avoiding the noise at the source. Several techniques were tested among which the suitable artificial lubrication of the wheel-rail surface was successfully leading to a noise reduction. The safety of the train operation is not affected by this method, as the braking system is in essence designed for the “natural” lubrication by the autumn leaves. Currently the approval of the federal authorities is aimed for.

2.6 - VIBRATIONS AND SECONDARY SOUND

Train movement on the track not only causes direct audible sound via transmission through the air but also sets off vibrations which are transmitted through the soil. Away from the railway line, these vibrations may reach a building thus creating both vibrations in the structure itself and also so-called secondary sound in the low frequency range due to the excitation of the walls and floors in the building.

At present legal specifications for tolerable vibration limits do not exist in Germany. Even so, some industrial standards and norms exist. In combination with the difficulty of forecasting, this results in some uncertainty concerning the vibration values to be aimed for during the planning phase of construction projects for various new railway lines or for upgrading exist-
ing lines. More or less reasonable error margins are taken into account to be "on the safe side" concerning later complaints by residents.

To overcome this uncertainty, the validation and application of numerical simulation models for vibrations is essential. The scope is wide-ranged in the sense that, from the train/track interaction through the transmission to the formation of the secondary sound in the house near the railway line, the simulation should give a reliable forecast. Also the effect of vibration protection walls buried in the ground has to be calculated with precision. Beside the physical modelling, the input information such as the material data of the ground is essential for the success of the simulation.

As an example, Figure 9 shows such an approach based on a complex spring-damper modelling of a track section creating ground vibrations during train passage. This physical model is used in the DB computer code RIM-Ground [7].

![Figure 9: Physical model of a track section creating ground vibrations during train passage in the RIM-Ground computer code](image)

The definition of suitable vibration limit values for residents is, of course, also vital to allow for more confidence in the planning procedures. Here, laboratory investigations with volunteers exposed to vibrations of the "railway-induced type" are underway and will form a data basis concerning the perception of, for example, the average and peak values and their spectral composition.

The results are used to set up a DB-internal guideline concerning the vibration protection e.g. for new lines under construction. But also the situation at existing lines is tackled. This guideline assists the civil engineering during the planning and construction phase of the infrastructure projects.
2.7 - REVISION OF GUIDELINES SCHALL03 AND AKUSTIK 04

The German acoustic-guidelines SCHALL03 (calculation rules for sound receiving near railway lines) and AKUSTIK04 (calculation rules for sound receiving near freight-train shunting yards and transhipment terminals) were released in 1990 by the legislative authorities [19]. Figure 10 demonstrates the basic physical model of the SCHALL03 for the calculation of the noise received by the residents. Both guidelines reflect measurements and investigations performed in the 80s.

![Physical modelling of sound receiving near railway lines according to SCHALL03](image)

In the meantime the railway traffic situation in Germany changed notably as among other modifications the high-speed trains came into operation which can only be tackled insufficiently by the existing guidelines. On the other hand the progress in the field of railway-acoustics research should enter the guidelines to keep them on a “state of the art” level both for the professional users and the residents near the railway lines.

To reflect this reasoning and to revise both guidelines the German federal authorities, lead by the ministry of transportation, are putting together a broad work-group consisting of environmental institutions, governmental as well as non-governmental, acoustic-engineering offices and (railway) transport undertakings. The acoustic specialists of DB were asked to enter this group with their expertise, too.

3. - CONCLUSIONS

DB is undertaking a major noise reduction research programme to answer the public demand for low-noise railway traffic in future. All aspects of the creation, the transmission and the perception of noise are being tackled in several projects by various workgroups launched with DB experts along with acoustic professionals from other European railway undertakings and external institutions.

4. - REFERENCES


The Hague, Netherlands, 2001


