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HIGH-SPEED TRAIN NOISE REDUCTION

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ABSTRACT
Protecting the environment, including reducing noise and ground vibrations from railways, has a very high priority at the DB AG. Extensive noise source investigations enabled noise reductions of ICE 1, ICE 2, as well as the new German high-speed train ICE 3. Above 100 km/h most of the noise is generated by wheels and rails, and at higher speeds than 300 km/h by aerodynamic sources. This overview discusses the most recent developments of identification and means of controlling noise from high-speed lines.

1 - INTRODUCTION
Despite the fact that railways generally perform well when the environmental impact of different carriers are compared, German Rail attaches considerable importance to its noise reduction strategies. Amongst its technological development targets, German Rail has set itself the goal of establishing an exemplary policy in the field of environmental protection. As a consequence, R&D projects must aim to reduce noise emission levels from rail vehicles and superstructures at source. The results of these investigations form the basis of tender and design specifications and can serve as a foundation for deriving the maximum acceptable emission levels for rail vehicles currently under consideration by the German Office of the Environment or the EU.

2 - NOISE EMISSION LEVELS OF THE CURRENT GENERATION OF RAIL VEHICLES
In order to be able to take effective noise reduction measures, the most important sources of noise must be located by conducting extensive and complex measurements [1]. The internationally standardized measurement point for acoustic emission measurements is 7.5 m or 25 m from the centre of the rails. The passage noise level comprises the noise radiation from all sources of vehicular- and track-based noise. In order to be able to compare the results of noise emission measurements made on various German Rail vehicles, the noise emission levels were converted to a speed of 80 km, see Figure 1.
According to these results, the quietest trains are the high-speed ICE trains equipped with disk brakes and wheel absorbers which have a noise emission level of 75 dB(A). Some 5 dB(A) louder are the Ellok (BR 2000, Schweiz), IC and IR trains, which are all vehicles fitted with disk brakes. The highest emission levels are recorded for those locomotives, passenger coaches and goods wagons which are equipped with cast iron block brakes and therefore suffer from wheel corrugations. The noise levels of these vehicles lie at or above 90 dB(A) which is equivalent to that from an ICE travelling at 300 km/h.
Noise emission levels can be significantly reduced by preventing wheel corrugations, i.e. by ensuring that the wheel running surfaces are smooth and by incorporating additional wheel absorbers.
The passage noise level, i.e. the sum of the rolling noise and the aero-acoustic noise, depends upon the speed of the vehicle. It can be demonstrated that both types of noise emission increase with increasing vehicle speed.
At speeds of up to 60 km/h, the dominant source of noise is traction noise from, for example, the traction motor blowers and the oil cooling fans. The rolling noise that radiates from wheels, track and sleepers is a major source of noise at medium speeds up to 280 km/h. At high-speeds aerodynamic noise becomes increasingly significant.

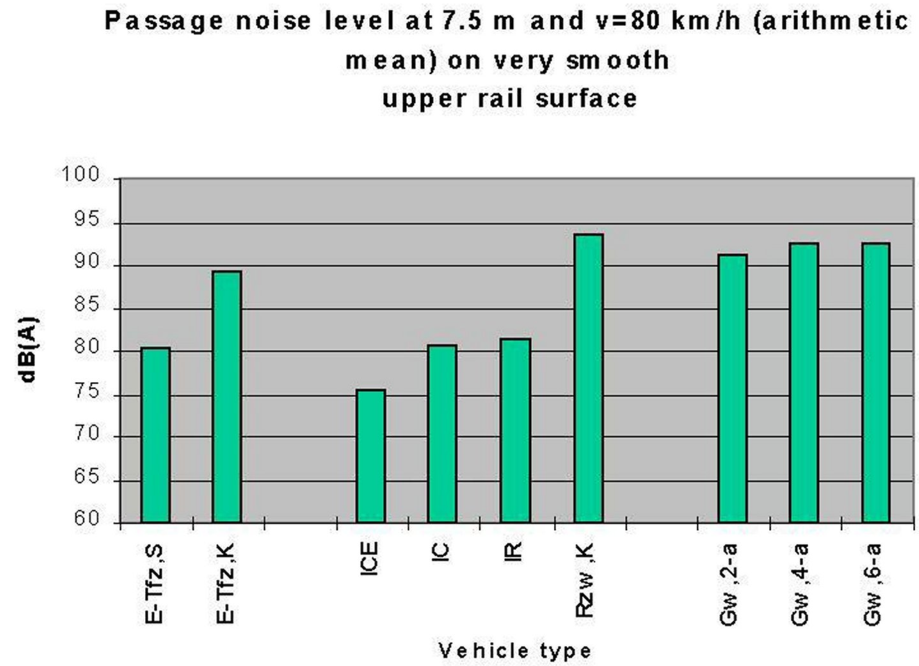

Figure 1: Passage noise level of rail vehicles (very smooth upper surface of rail).

The passage noise level due to the rolling noise generated by the wheels on the track is approximately proportional to the third power of the running speed:

$$\Delta L_A = 10 * \alpha_1 * \log v/vo, \qquad \alpha_1 = 3,\ v = \text{train speed},\ v_o = \text{ e.g. } 100\text{km/h}$$

The aerodynamic noise is the result of the interaction of the vehicle body with the turbulent flow boundary layer and the flow separation and vortex shedding that occurs at the front and rear of the vehicle as well as on individual vehicle components such as the bogies and the current collector support structures on the roof. Measurements have shown that the level of aerodynamic noise is proportional to the sixth power of the vehicle speed:

$$\Delta L_A = 10 * \alpha_2 * \log v/vo, \qquad \alpha_2 = 6,\ v = \text{train speed},\ v_o = \text{e.g. } 280\text{km/h}$$

The noise emission data mentioned above was measured for vehicles travelling on very smooth track. When the upper surface of the rail becomes corrugated, noise levels can increase dramatically. Therefore from the point of view of controlling train noise, the condition of the upper surface of the rails is becoming increasingly significant.

3 - REDUCING THE ROLLING NOISE OF RAIL VEHICLES

Besides the smoothness of the wheel running surfaces, the most important factor determining the rolling noise is the condition of the upper surfaces of the rails. The noise emission level from a rail vehicle is crucially dependent upon surface roughness of the track in the wavelength range 1 cm to 10 cm. The smoother the rails in this wavelength range, the lower the degree of sound radiation.

In March 1998, the Federal Railway Office approved the SMT inspection procedure (SMT = Specially Monitored Track) for the German Rail track system [2]. The procedure involves grinding certain sections of track using a special grinding technique, regularly testing the acoustic behaviour of these sections with a specially developed acoustic measuring vehicle and, when necessary, re-grinding. By employing the SMT approach, a reduction of 3 dB can be incorporated when calculating noise emission levels as part of the planning procedures for the construction of new track or the extension of existing track, a fact which allows considerable savings on conventional noise abatement measures to be made.

4 - REDUCING THE AEROACOUSTIC NOISE OF RAIL VEHICLES

Of particular significance for high-speed rail traffic is the aero-acoustic noise generated by current collectors. Sound protection walls, which typically extend to a height of 2 m above the track, are unable to reduce sound emissions from the higher lying current collectors.

Noise emissions from current collectors on high-speed trains may well become a serious problem in future if, for example, one considers the multi-system version of the ICE 3 in which the number of current collectors on a single train may be increased to twelve.
As part of the Franco-German project "Deufrako" (Appendix K), the sources of noise on high-speed trains were determined. The noise emission sources of the ICE 1 are shown in Figure 2.
References [3,4,5] provide a comprehensive survey of the information that has been obtained from array measurements and of the most recent results on noise source localization on high-speed trains.

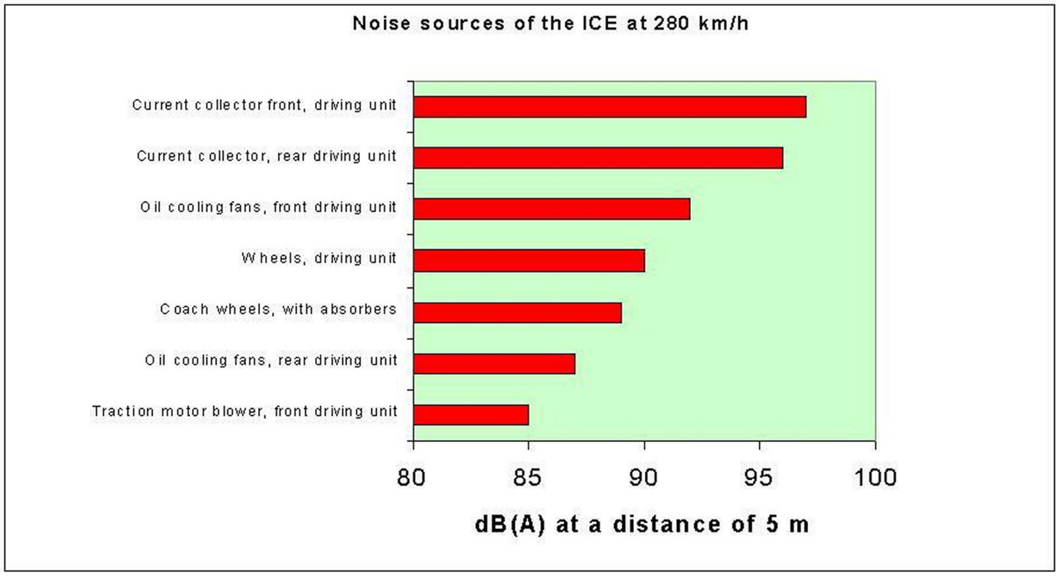

Figure 2: Noise sources of the ICE at 280 km/h.

The localization and identification of the noise sources of the ICE, TGV-A and TR 07 employed an array technique, i.e. the simultaneous use of a large number of microphones. A number of different array geometries were used, including one-dimensional (linear) arrays and two-dimensional configurations such as the crossed array consisting of two intersecting linear arrays and planar arrays. A microphone array can be used for noise source localization because it functions as a highly directional receiver.
Experiments carried out in the acoustic wind tunnel facility in Braunschweig as part of the Deufrako project (Appendix K 2) enabled means of minimizing noise emissions from individual components of the current collector to be determined.
Because the fan in the Braunschweig wind tunnel is of limited size (1.2 m by 0.8 m), only individual elements of the current collector could be aero-acoustically measured. It was therefore important to use the German-Dutch wind tunnel to determine the noise produced by a complete collector.

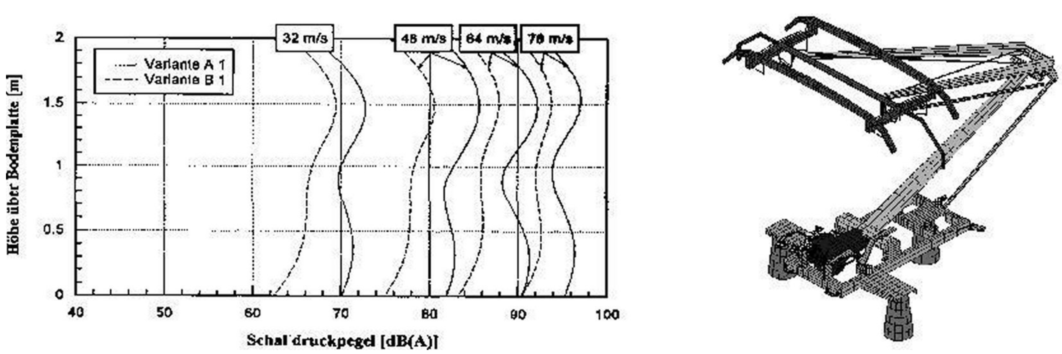

Figure 3: Wind tunnel measurements on a DSA 350 SEK current collector with (variant B1) and without (variant A1) noise reduction measures.

At the German-Dutch wind tunnel, acoustic measurements were performed on a number of current collectors provided by industry. The measurements used individual microphones and a vertical arrangement

(array) of microphones and were carried out on three types of collector: the DSA 350 SEK normal and optimized, the DSA 380 D and the SSS 87.
The German-Dutch wind tunnel has a fan with an area of 8 m by 6 m. In these experiments, the wind speeds selected were 115 km/h, 172 km/h, 230 km/h and 280 km/h. In all cases the background noise level was separated sufficiently from the measurement signal.
Measurements in this facility may become problematic if the current collectors become about 15 dB(A) quieter than present models.
The cladding added to the base of the DSA 350 SEK current collector resulted in a noise level reduction of approximately 6 dB compared to the unclad version.
Aero-acoustic improvements to the pantograph head, without requiring design modifications to the collector, gave rise to a reduction of about 4 dB(A).
Excellent agreement was achieved between the results of the measurements carried out in the two wind tunnels into the effects of the noise protection measures.
Individual components such as the horn and the uplift stop on the current collector could be distinguished as sources of noise in the acoustic spectrum and could be eradicated by suitable remedial measures. This suggests that the noise emission from the knee constitutes only a minor fraction of the total noise radiation, those this will no longer be the case once further improvements have been made to the head and foot regions
When the individual current collector types are compared, it can be stated that at a wind speed of 280 km/h and a distance of 5 m, the three other current collectors were approximately 4 dB(A) quieter than the DSA 350 SEK in its normal configuration.
The results obtained in the wind tunnels were essentially confirmed by measurements performed on the high-speed section of track between Hanover and Göttingen. However, the 4 dB reduction in the noise level that was achieved is insufficient.
If the effectiveness of the noise protection wall is not to be diminished by higher-lying sources of noise, then a noise reduction factor of more than 10 dB will be required. Relevant investigations are already underway and will be presented at this meeting [6,7].

5 - SUMMARY AND OUTLOOK

Increasingly, demands are being made to implement noise reduction measures at source, i.e. on the vehicle and on the superstructure.
It is worth emphasizing that noise reduction measures at source not only benefit local residents, but also passengers. A further aspect is the possibility of reducing the height of noise reduction walls in certain areas.

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