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SOUND EMISSION LIMITS FOR RAIL VEHICLES

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The statistical evaluation of measured sound emission levels from individual rail vehicles enables a clear distinction to be made between disc-braked passenger vehicles with and without wheel absorbers and tread-braked vehicles equipped with cast-iron brake blocks. A retrofit programme for replacement of cast-iron blocks by composite (K-, L- or LL-) blocks seems feasible within the next five years. The performance and durability of the new brake blocks provides a substantial noise reduction at no or limited additional costs, depending on the need for new wheels. Additional wheel damping is desirable but not readily available at sufficiently low cost. Based on the experience from an experimental train equipped with a quiet locomotive, bogie shrouds and matching low-profile barriers along the track, sound emission limits are proposed which are described in two steps.

1. INTRODUCTION

An investigation carried out for the German Federal Environmental Agency (UBA) was aimed at compiling technical and organizational means for the efficient and economic control of noise from railway traffic. Both freight traffic, which is the major source of annoyance during night-time, and local, regional and long-distance passenger traffic had to be addressed. An important aspect of this study was pass-by noise. Ultimately, sound emission limits of railway vehicles should be determined that provide the basis for a German proposal to the European Commission.

2. SITUATION

Over the past 30 years, extensive research has resulted in detailed information about the sources of sound and the potential means of noise control for rail vehicles. The practical implementation, however, is limited by a number of factors. Rail traffic in Europe is international. Consequently, regulations require harmonized activities at a technical feasible level internationally, particularly for long-distance traffic. The time scale is of major importance. Many vehicles have

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a lifetime of about 40 years. Since noise control is needed in the more immediate future, the design of quieter cars is not sufficient; retrofit action is required for existing cars. Depending on the effort spent on such measures, different steps must be devised for action plans.

Such action plans have been established in Switzerland [1], Austria [2] and Italy [3]. The Swiss regulations on "Noise emission limitation of rolling stock" are limited to new passenger cars and powered vehicles. The Austrian rail vehicle noise code of 1993 contains a complete plan for both existing and new vehicles until the year 2002 based on acoustical experience for different types of vehicles. The draft Italian regulations propose the implementation of noise control in two stages. They conform with the current situation and are scheduled for the years 2002 and 2012.

The rather modest requirements on improved noise control written in most of the specifications for new locomotives and other powered vehicles represent only the start of low-noise design for rail vehicles. They are not compatible with the existing low-noise reception limits. Therefore, noise barriers and sound-proof windows have been used in the past alongside new or modified railway lines. However German Railways (DB AG) has shown for an experimental train, that by use of common noise control measures applied to vehicles and low barriers in combination with vehicle shrouds, more effective noise control can be achieved at comparatively low costs [4]. Based on this experience, substantially lower noise emission limits are justified than those which are currently observed for existing rolling stock.

3. INVESTIGATION

3.1. OVERVIEW

The investigation considered

- descriptors for the sound emission of vehicles;
- existing data on pass-by levels of individual vehicles in trains;
- noise control measures applicable in the short term;
- number of vehicles and costs of noise control measures;
- proposals for noise emission limits.

The investigation of pass-by levels was mainly based on recent systematic measurements carried out by Müller-BBM for DB AG as well as on data published in recent years. In addition, the Advisory Group for the project and the communication in special Workshops and with individuals provided for valuable input. The DB AG Environment Center (BUZ) in Berlin and the Research and Technology Center (FTZ 81) in Munich assisted in this area as subcontractors.

Questions concerning the number of vehicles and the costs for retrofitting have been worked on under subcontract by Ifo Institute for Economical Research in Munich. Published data relating to the present fleet of cars and on those planned for the future have been used. Cost estimates proved to be difficult at DB AG due to new evaluation systems which are not yet fully functional.

3.2. EMISSION DESCRIPTORS

It is important that the descriptor for the sound emission from vehicles of all types is widely accepted. It is proposed that the A-weighted sound power level per unit length $L_{W'A,100\ \mathrm{km/h}}$ measured at the maximum operating speed and converted to 100 km/h using a conversion rate of 30 dB per decade should be used. The A-weighted sound power level is the descriptor commonly used for machinery and plants. The conversion to the unit length is related to the number of wheels which are the important sound sources. For individual powered vehicles and for complete trains, the level $L_{W'A,V_0}$ is calculated from the single event level $L_{pA,1s,V}$ measured at the velocity V by

$$L_{W'A,V_0} = L_{pA,1s,V} + 10\lg\left(\frac{2V_0t_0}{d_0}\right)\mathrm{dB} + 10\lg\left(\frac{d}{l}\right)\mathrm{dB} + 20\lg\left(\frac{V_0}{V}\right)\mathrm{dB}, \quad (1)$$

where $V_0 = 100$ km/h, $d_0 = 1$ m, $t_0 = 1$ s, d is the distance of the microphone from the track centreline (preferably 7·5 m) and l is the length of the individual vehicle or the entire train. The second term yields about 17 dB.

For unpowered vehicles, the level $L_{W'A,V_0}$ is calculated from the equivalent level $L_{pAeq,T,V}$ measured at the velocity V by

$$L_{W'A,V_0} = L_{pAeq,T,V} + 10\lg\left(\frac{2d}{d_0}\right)\mathrm{dB} + 30\lg\left(\frac{V_0}{V}\right)\mathrm{dB}. \quad (2)$$

The sound power level per unit length is related to the transit exposure level (TEL) by

$$L_{W'A,100\ \mathrm{km/h}} = TEL_{7\cdot 5\mathrm{m},80\ \mathrm{km/h}} + 15\,\mathrm{dB}. \quad (3)$$

In the draft version of ISO 3095 [5], the level TEL is the preferred descriptor, since it is lower in number than $L_{W'A,V_0}$ and is easier to explain to non-acousticians.

Powered vehicles should be measured under the full-load condition, and unpowered vehicles measured according to the draft of ISO 3095 in pairs at least and with similar vehicles on both ends. The one-third-octave-band level of railhead roughness, L_r, averaged over a width of about 20 mm should meet the requirement

$$L_r \leqslant \left[4 - 6\lg\left(\frac{\lambda_0}{\lambda}\right)\right]\mathrm{dB}, \quad (4)$$

where $\lambda_0 = 1$ m, λ is the band-center wavelength in the range $0{\cdot}2\,\mathrm{m} \geqslant \lambda \geqslant 0{\cdot}005\,\mathrm{m}$, and L_r is referred to 1 μm.

3.3. FIELD DATA FOR INDIVIDUAL VEHICLES

From measurements carried out at three locations in Germany with well-controlled track conditions, a substantial amount of emission data is available. The results presented in Table 1 show the well-known differences between vehicles equipped with cast iron tread brakes, disc brakes and additional wheel absorbers. Average sound power levels per unit length of 107 dB are typical for unpowered

TABLE 1

Mean value and standard deviation of the A-weighted sound power level per unit length during pass-by of rail vehicles

Type of vehicle	No. of measurements	$L_{W'A,100\ \mathrm{km/h}}$ (dB)	Std. dev. (dB)
E-powered vehicles			
Disc braked	30	95	2·0
Cast iron tread braked	171	104	2·2
Passenger vehicles			
ICE	150	90	2·2
IC	387	95	1·6
IR	100	96	2·2
Cast iron tread braked	147	108	2·4
Freight vehicles			
2-axles	506	106	2·1
4-axles	1387	107	2·1
6-axles	176	107	1·6

vehicles equipped with cast iron tread brakes, while 3 dB lower levels apply for powered ones. 95 dB and 90 dB is the average value for disc-braked vehicles without and with wheel absorbers, respectively. It is worthwhile noting the standard deviation of about 2 dB for all types of vehicles. According to DB AG, this is presumably due to random effects of braking. Histograms of A-weighted sound power levels (not referred to unit length) are shown in Figure 1.

Sound power levels per unit length have been estimated from measurements carried out by STUVA [6] in 13 different German towns on about 10 different types of rapid transit trains, street cars and subway vehicles at distances of 7·5 and 25 m running at speeds of 40 and 60 km/h. The results given in Table 2 show a substantial standard deviation due to the difference between ballasted and grass-covered track beds, and for vehicles with and without sound absorbent shrouds.

A Müller-BBM data base which includes data from other detailed measurements shows that the sound power levels per unit length for subway trains are slightly higher than those from full-size disc-braked rail vehicles. Street cars and rapid transit trains are considerably louder depending on the noise control measures applied. The information from UBA listed in Table 2 is based on maximum pass-by levels and, consequently, involves some uncertainty after conversion to sound power levels per unit length.

3.4. SHORT-TERM NOISE CONTROL MEASURES

3.4.1. *Powered vehicles*

New electric locomotives for freight and passenger trains can be equipped with disc brakes or non-cast-iron tread brakes according to the state-of-the-art without

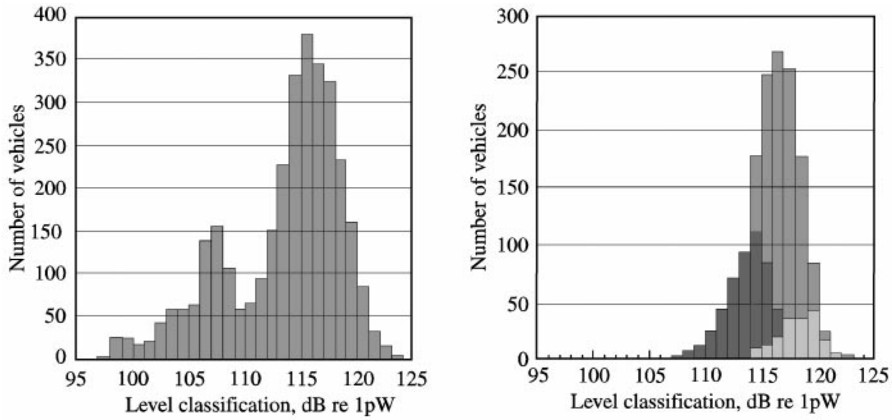

Figure 1. Histogram of measured A-weighted sound power levels, converted to a reference speed of 100 km/h; left-hand side: all measured vehicles, right-hand side: freight cars only with 2 (black), 4 (dark grey) and 6 axles (light grey).

TABLE 2

Mean value and standard deviation of the A-weighted sound power level per unit length for passing urban rail vehicles

Type of vehicle	No. of trains	$L_{W'A,100\,\mathrm{km/h}}$ (dB)	Std. dev. (dB)
Measurements by STUVA			
Subway	5	96	1·5
Rapid transit train	14	100	3
Date base Müller-BBM			
Subway	25	95	2·1
Rapid transit train	88	98	1·7
Street car	552	99	3·4
Information by UBA			
Subway Hamburg, Berlin		93–97	
Rapid transit train Hannover		100–102	
Rapid transit train Stuttgart		96–98	
Street car Berlin GT6		99–101	

essential increase in cost [7]. The rolling noise is then no louder than that from disc-braked cars. Sound radiated from the wheels originating from gears and rolling can be reduced by sound absorbing shrouds. However, on existing vehicles such measures may be impractical due to spatial limitations and high costs.

Additional measures are needed on powered vehicles used for high-speed traffic in order to reduce the aerodynamic noise from the pantograph, roof structural elements and grids covering intakes for cooling air. They are presently being tested and will be available for new vehicles.

Electric and diesel-powered locomotives emit fan and turbo-suction noise which is most relevant during acceleration up to 120 km/h. It can be muffled using state-of-the-art techniques by 10 dB. Gear noise can also be reduced by 10 dB by using modified gears and enclosures. Loud macro-slip noise observed on vehicles equipped with modern control units for maximum traction power can be reduced by reducing the efficiency of the control slightly. Engine and exhaust noise from current diesel engines can be reduced by improved enclosures and silencers by 5–10 dB. Under-floor traction units for future diesel-powered trains should be equipped with integrated enclosures similar to road traffic vehicles.

Wheel absorbers and sound absorbent shrouds should be specified for new subway vehicles, rapid transit trains and street cars.

3.4.2. *Unpowered vehicles*

An agreement has been reached between CER, UIP and UNIFE to retrofit all cast-iron tread-braked freight vehicles with composite blocks during regular maintenance activities over the next years. A reduction in the sound emission level of 8–9 dB is expected. Modification of the brake rigging is required as long as K-(composite) brake blocks are applied. In the future, L-(low friction) or LL-brake blocks will be available which need no further modifications. The increased heat creation in the wheel caused by the new brake blocks and the different speed dependence of their friction coefficient may require the replacement of standard wheels by “low-tension” wheels where the thermal expansion does not lead to high tension in the wheel rim which is sensitive to micro-fissures.

In addition, DB AG has proposed to equip the wheels of freight cars with damping rings. When applied to one side of the wheel excess attenuation of 2–3 dB was expected. However, these data result from experimental findings which need further confirmation and have not been taken into account when deriving the noise emission limits.

The same measures are applicable to passenger vehicles presently equipped with cast-iron tread brakes. Disc-braked vehicles can be improved by damping rings or elements similar to those mounted on ICE wheels. In the long term, DB AG is planning to develop a low-noise technology which should reduce current sound emissions by 3 dB within the next 10 years [8].

The combination of noise shrouds with special low-profile barriers should yield an additional reduction ranging from 4 dB for locomotives to at least 6 dB as already demonstrated by experiment for unpowered cars. Shrouds and barriers must form an enclosure with not more than 10% open area and include sufficient internal absorption.

3.5. NUMBER OF VEHICLES AND COSTS OF NOISE CONTROL MEASURES

The total number of cast-iron tread-braked vehicles in Europe is close to 2 million. In Germany more than 100 000 freight cars owned by DB AG, 60 000 privately owned freight cars and 4000 passenger cars for regional traffic require retrofit. In addition, about 5000 disc-braked passenger cars used for long-distance traffic may be equipped with wheel absorbers similar to those mounted on ICE trains.

TABLE 3

Preliminary proposal for emission limits in two Steps of noise control to be measured on a test track with low surface roughness conforming to equation (4)

Type of vehicle	Step 1			Step 2
	$L_{W'A}$ 100 km/h (dB)	TEL 80 km/h, 7·5 m (dB)	$L_{AFmax,}$ 80 km/h, 7·5 m (dB)	ΔL_{add} (dB)
Standard gauge railway				
Locomotives	**95**	80	77–81	– (4 + 4)
Powered vehicles	**93**	78	79	– (4 + 4)
Unpowered tread-braked vehicles	**95**	80	81	– (5 + 6)
Unpowered disk-braked vehicles	**90**	75	76	– (2 + 6)
Local transportation				
Subways, rapid transit trains	**93**	78	79	– (4 + 4)
Street cars	**93**	78	79	– (4 + 1)

The acoustic retrofit of a vehicle with disc brakes (including labour and material) costs about twice as much as new cast-iron tread brakes and is therefore not economically viable. Even half of the cost of disc brakes, which would be needed for drum brakes, is considered too high. Only retrofitting with different tread brakes is feasible within regular maintenance at costs of 17€ per brake block. Although composite blocks are about twice as expensive as cast-iron blocks, the former last at least three times longer [9]. Within a period of 10 years, accounting for the modification of the brake system as well as application of low-price damping devices, a balance of expenditure and saving is estimated.

Excess costs for noise control measures on new powered vehicles, e.g., by means of low-noise gears, silencers, enclosures and shrouds, could not be determined separately. By early integration of noise control at the design stage, the costs are negligible in the experience of the manufacturers.

4. EMISSION LIMITS

Discussions with DB AG and UBA which were based on the application of the best acoustical technology as used for ICE cars and demonstrated for other vehicles, resulted in the preliminary proposal for noise emission limits listed in Table 3.

Step 1 is related to retrofit of unpowered vehicles with composite brake blocks and wheel damping. Emission limits in Step 1 for existing powered vehicles need special consideration. In Step 2, the first number in Table 3 gives the level reduction expected from measures on the vehicle and the second number the additional effect of a low barrier. Step 2 should be considered in specifications for all new vehicles.

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