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Train noise reduction scenarios for compliance with future noise legislation

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Abstract

The Technical Specification for Interoperability (TSI) for high-speed trains on the European market includes limits on noise emission. These and other future restrictions on exterior noise of high-speed and intercity trains will require that train manufacturers implement noise control measures early in the design phase.

A fundamental problem faced by manufacturers during the design process is determining how much noise reduction is required for each of the various noise sources on the train in order to achieve an optimal balance. To illustrate this process, estimates are presented of the contributions from different sources on existing Bombardier trains, based on measured data, numerical calculations and empirical formulae.

In addition, methods of achieving the required noise reductions for different sources are briefly discussed along with targets for future exterior noise emission.

Measurement results presented demonstrate the importance of track quality in noise emission. Noise restrictions, including future legislation, must give proper recognition to this important parameter.

1. Introduction

The trains of tomorrow can and must be quieter. The questions are, how much quieter, by which noise control means and at what cost? Train manufacturers will have to find measures to meet future customer requirements for exterior as well as for interior noise. Exterior noise requirements will be based on the levels that can be anticipated in future European noise legislation.

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It is of great importance to find cost efficient solutions for noise control, both in order to be competitive as a train manufacturer and to keep the railway business as a whole competitive. This means that efficient noise control measures must be implemented early in the design phase, and an optimal balance must be found for controlling the various noise sources on the train. It may also mean that new solutions and technology will have to be accepted by the railway community.

This paper first briefly reviews in Section 2, the levels suggested in future noise legislation. In Section 3 some results on the influence of track-wheel condition on rolling noise levels for a new intercity train are shown. The contribution of rolling noise from the train and the track is confirmed with Track Wheel Interaction Noise Software (TWINS) calculations [1,2], and estimated levels for aero-acoustic sources at higher speeds are added. Section 4 is devoted to one of the more important aero-acoustic sources at higher speeds, especially the pantograph, and preliminary results from wind tunnel testing of a new low-noise pantograph are summarized. Finally, a possible scenario for exterior noise emission from a future train is evaluated in Section 5, assuming that best practice and some new technology is systematically implemented for all sources.

2. Future noise legislation

The Technical Specification for Interoperability (TSI) for high-speed trains in Europe includes limits on noise emission. The TSI has been in force since December 2002 [3]. The main content is shown in Table 1.

Work on a TSI on noise for conventional rail has also started and standards should be drawn up before April 2004 according to a directive from 2001 [4]. A TSI on noise has been identified as one of the first priorities in the Directive. An expert group on noise within Association Européen de l'Interopérabilité Ferroviaire (AEIF) will play a significant role in the development of this TSI. A proposed strategy for the future EU policy on railway noise abatement was published by a consortium led by Ødegaard and Danneskiold-Samsøe on a contract from the European Commission [5]. In addition levels for conventional trains were proposed by Union Internationale des Chemin de Fer (UIC) [6] as listed in Table 2.

The measurements of exterior noise should be performed according to the draft prEN ISO 3095:2001 [7]. The applicability of this draft standard has been evaluated by TNO (Netherlands Organisation for Applied Scientific Research) [8]. It was concluded that the standard is only

Table 1
TEL for high-speed at 25 m distance

TEL, dB(A), at 25 m ($h = 3.5$ m)	High-speed train (HST) sets			
Speed	250 km/h	300 km/h	320 km/h	350 km/h
TSI HST 2002	88 ($87+1^{a}$)	92 ($91+1^{a}$)	93 ($92+1^{a}$)	—
TSI HST 2005/2008	86	89	90	92

[a] A margin of 1 dB(A) is tolerated until adoption of next generation TSI, taking into account that the measurement conditions and the description of the reference track are still under discussion at the time of the adoption of the present TSI.

Table 2
Proposed TEL for conventional EMUs and DMUs [5]

TEL	Conventional railway systems, EMUs and DMUs, values for 80 km/h, cubic speed dependence	
Distance	7.5 m	25 m
UIC proposal [5]	81	74
ODS propsal [4]	80	73

sufficient for noise emission legislation if the track conditions are more tightly specified. In the TSI for high-speed trains additional requirements on track parameters have been added, including a modified railhead roughness and specified static pad stiffness with preload or the use of an acoustically equivalent track design. The present formulation will however be very difficult to handle in practice for type testing of new vehicles on a normal track where the pad stiffness is almost always lower than the one specified in the TSI.

The next Section shows results of noise emitted by the same type of train on the same track section but with different track surface quality.

3. Rolling noise—intercity trains up to 200 km/h

Several measurement campaigns have been conducted in connection with type testing of the Regina and Contessa Trains from Bombardier Transportation. Contessa, shown in Fig. 1, is a train which runs over the Øresund Bridge between Denmark and Sweden. Regina, shown in Fig. 2, is a wide-body intercity train. The first Regina trains are delivered to Swedish operators in 2-car configurations. All wheels on the Regina are equipped with cheek-mounted disc brakes and no wheel dampers. Three of the four bogies are driven.

3.1. Measurements on Regina: Autumn 2000

The initial measurement of exterior noise was carried out during Autumn 2000. A typical pass-by from Regina at 200 km/h registered by one microphone at 5 m is shown as a spectrogram in Fig. 3. Wheel–rail noise dominates the pass-by noise in this case: the three dominant peaks in the plot are associated with passage of the 4 bogies. The ridge in the 1250 Hz band is due to rail radiation with propagating waves, which have a low rate of decay. It is interesting to note, however, that even at this low speed the pantograph contribution is evident in the 200 Hz band, as indicated by the arrow.

Vortex shedding around the contact strip of the pantograph head gives a speed dependent tone at $f = St \cdot V/d$, where f is the frequency, St the Strouhal number, V the velocity in m/s and d the typical dimension of the object producing the vortex. In this case the equation yields a frequency of approximately $f = 0.19 \cdot 55/0.05 = 209$ Hz.

Measured noise levels for several speeds up to 200 km/h are shown in Fig. 4. The curve for total level was calculated from estimated levels of the contributions from the wheel–rail and the

Fig. 1. Contessa OTU four-car intercity train.

Fig. 2. Regina wide-body two-car intercity train.

aero-acoustic sources. It is assumed in this exercise that the difference between L_{Aeq} and transient exposure level (TEL) is small, normally below 1 dB, and all levels shown are approximate.

The customer requirement in this case for a limit of 88 dB(A) at 180 km/h was easily met. However, it is clear that this train–track combination will not meet the proposed UIC limits for conventional trains, nor the TSI for high-speed trains if levels are extrapolated to higher speeds. The question then arises as to whether the Regina train is far too noisy in relation to proposed new restrictions. The following results show that this is not necessarily the case.

The condition of the track was measured and found to have a medium roughness [9], slightly above the requirements set by prEN ISO 3095:2001, as shown in Fig. 5. The track was a typical new Scandinavian track with low pad stiffness, consisting of UIC 60 rails fixed to concrete sleepers set in stone ballast.

3.2. Measurements on Regina: Summer 2001

A second set of exterior noise and rail roughness measurements was carried out during Summer 2001, on the same line at the same test site and with the same type of train, in conjunction with

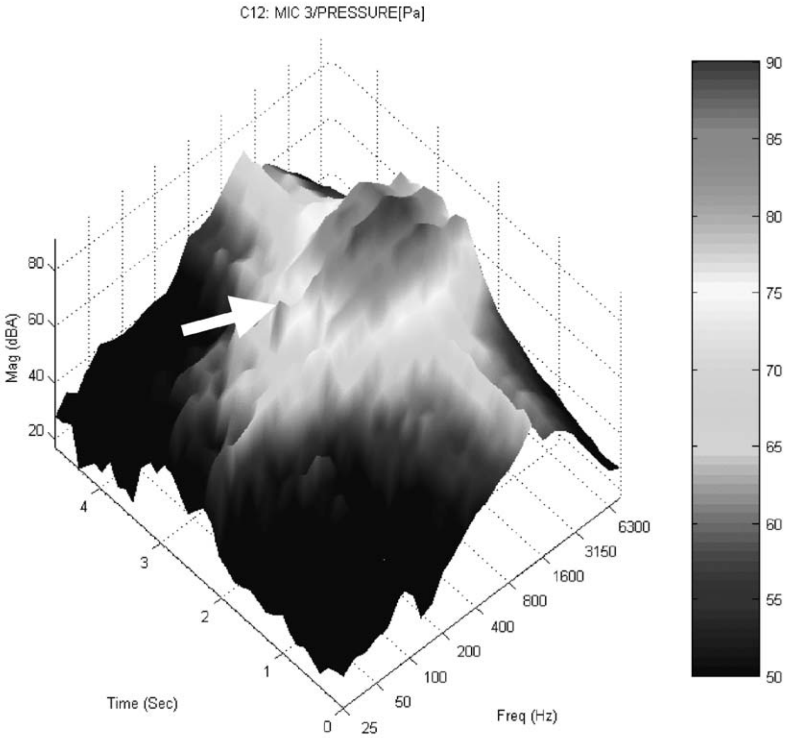

Fig. 3. Pass-by sound pressure level in dB(A) at 200 km/h, 5 m, Regina, medium quality track.

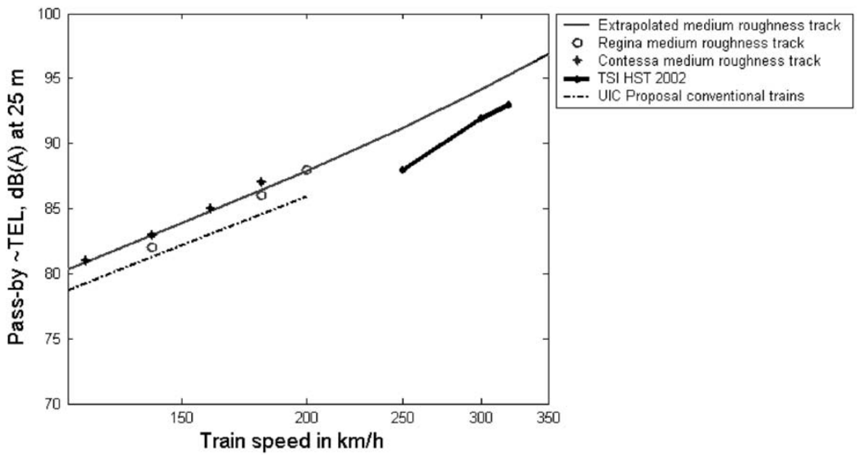

Fig. 4. Pass-by noise on medium quality track for Regina and Contessa OTU.

interior noise type testing. Noise levels were found to be 4–5 dB lower for both exterior and interior noise. The results for the exterior noise are shown in Fig. 6. Extrapolation indicates that the levels at higher speeds would fall on to roughly the same curve as those from measurements on

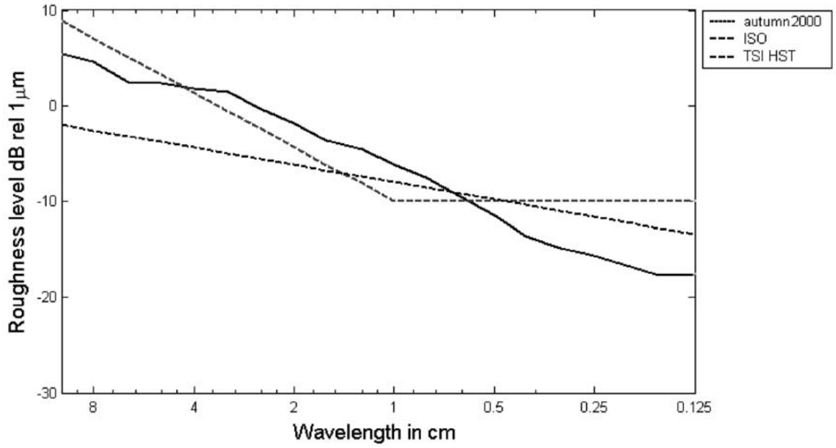

Fig. 5. Rail roughness spectrum, Autumn 2000.

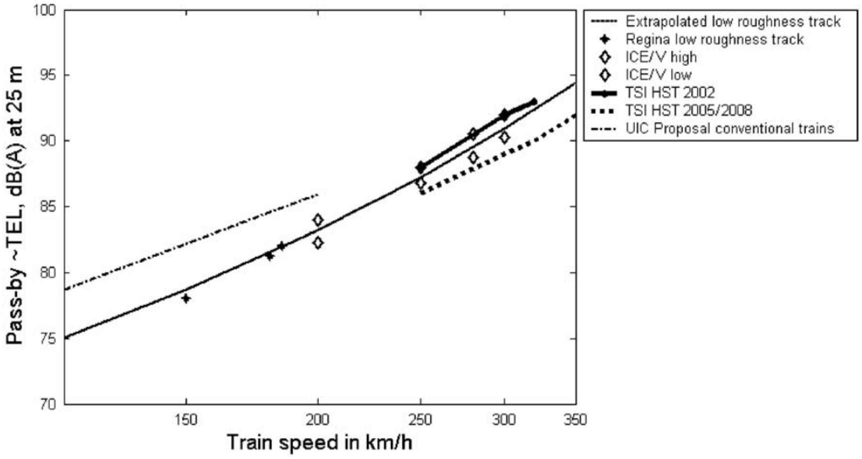

Fig. 6. Pass-by noise with current good practice on low-roughness tracks compared with short-term requirements.

the ICE-V (German ICE-prototype train) [10]. Furthermore, the TSI requirements for high-speed trains can be met if the data are extrapolated, as can the UIC proposal for conventional trains.

The following relations were used for constructing the curve shown in Fig. 6; that is, for estimating the relative contribution of wheel–rail versus aero-acoustic sources on an electrical multiple unit (EMU) train with speed V:

$$\text{Wheel–rail: } L_{pA,TEL}(25\,\text{m}) = 82 + 30\log\left(\frac{V}{200}\right)\ \text{dB(A)},$$

$$\text{Aero-acoustic sources: } L_{pA,TEL}(25\,\text{m}) = 77 + 65\log\left(\frac{V}{200}\right)\ \text{dB(A)}.$$

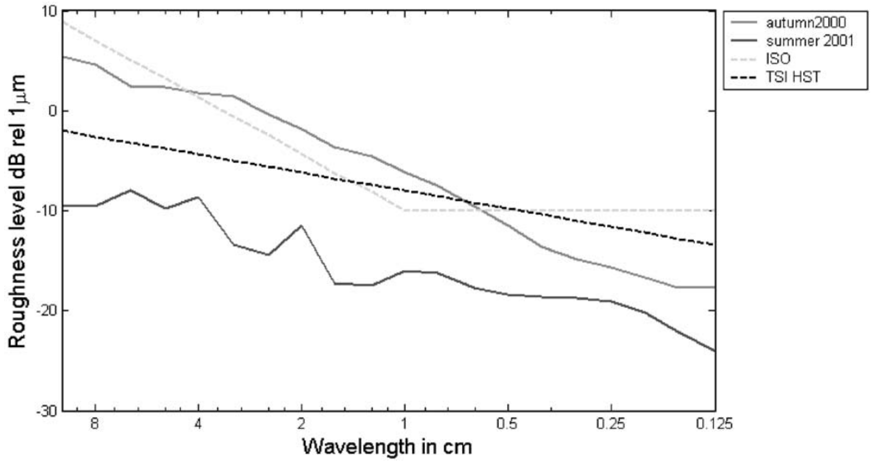

Fig. 7. Rail roughness spectrum, Summer 2001 lowest line.

The rail roughness was re-measured [11] and found to be considerably lower than during the Autumn 2000 measurements, due to grinding of the track. It was now well below the levels required in prEN ISO 3095:2001, as shown in Fig. 7. The fact that the train was essentially the same in the two test campaigns suggests that it was primarily the improved track condition that led to satisfaction of these limits. TWINS calculations were performed to confirm this suggestion.

3.3. TWINS calculations

Different train sets were used in the two measurement programmes, but both were new trains of the same type, with disc-braked wheels, recently delivered to customers. Wheel roughness is therefore expected to be reasonably low and of the same order of magnitude for the two different measurements.

Calculations of the sound power from the wheel–rail interaction were performed with TWINS for the two different roughness spectra in Fig. 7 combined with wheel roughness from Ref. [12] and contact filtering. The results, shown in Table 3, indicate a reduction in sound power level of 4 dB, which correlates fairly well with the measured reduction in sound pressure level.

An example of the output from TWINS calculation with a Matlab interface is shown in Fig. 8 for a medium roughness case at 300 km/h. These results show that with the soft pads on this Scandinavian track the rail dominates the total A-weighted sound power level.

The relative contribution from wheel and rail to the total sound power level was computed for different speed and pad stiffness values, with the results summarized in Table 4. A rail-pad loss factor of 0.25 was used [13]. The TWINS spectra include the integrated sound power from an infinite rail. Consequently the relative contribution of the rail is slightly overestimated, compared to that estimated from wayside sound pressure measurements. It is assumed, however, that the results give a reasonable indication of the relative importance of the different sources.

Table 4 shows that on soft pads the rail either dominates or makes a strong contribution to the overall level. For stiff pads, the wheel and rail contributions are approximately equal. These relationships are important for estimating the effect on the overall levels of control measures applied to the train.

Table 3
TWINS calculations for two different rail roughness values, total sound power levels in dB(A)

	Sound power dB(A)
Medium rail roughness, Autumn 2000—Fig. 5	114
Low rail roughness, Summer 2001—Fig. 7	110

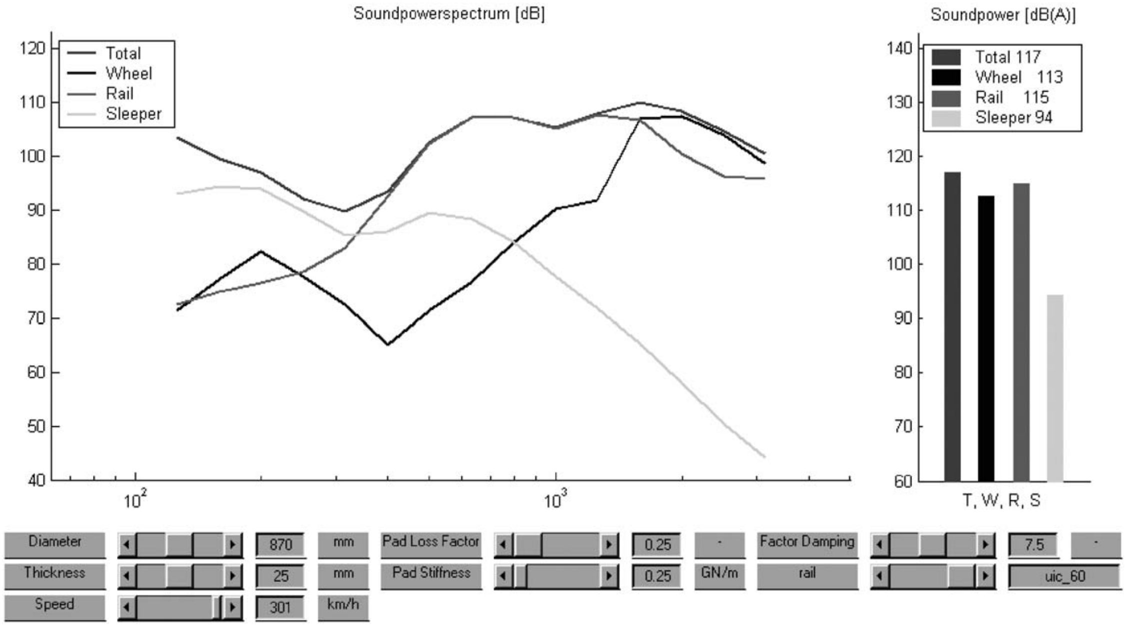

Fig. 8. Relative contribution from wheel and rail-sleeper according to TWINS with soft pads.

Table 4
Relative contribution from wheel and rail and total noise according to TWINS, with medium roughness and disk-braked wheels for different pad stiffness and speed; values in A-weighted sound power

Dynamic vertical pad stiffness GN/m	200 km/h, damp factor 7.5		300 km/h, damp factor 7.5	
Soft 0.25	Overall = 114		117	
	$W = 108$	$R = 112$	113	115
Stiff 1.25	111		116	
	108	108	113	112

Furthermore, Table 4 shows that the reduction in overall levels going from soft to stiff pads is 3 dB at 200 km/h and 1 dB at 300 km/h. This corresponds to a considerable difference in rail roughness, as illustrated by the results in Table 3.

According to tests on a Bombardier train in Norway [14], damping of the wheels may also to some limited extent reduce the vibration of the rail and hence the rail-radiated sound power. More efficient wheel dampers may thus be a possible control measure for reducing the overall rolling noise further, compared to the current levels estimated in Fig. 6. The anticipated benefit, however, is limited to 1–2 dB, since the wheels with cheek-mounted disc brakes on the Regina are already highly damped. The same is true for the wheels on the ICE that are already fitted with dampers.

Bogie shields can reduce wheel-radiated noise by 3–4 dB [15]. This would result in a reduction of approximately 2 dB in the overall level with stiff pads, and 1 dB with soft pads for the examples in Table 4.

Hence, the total wheel–rail contribution would be reduced by a further 1–2 dB with the introduction of bogie shields or more efficient wheel dampers. Bogie shields have other attractive properties as well, such as controlling aero-acoustic noise generation, reducing drag and presenting an attractive appearance.

4. Low-noise pantograph

The pantograph is an important noise source at higher speeds. This is particularly true for EMU trains, which can include up to 6 pantographs on a 200 m train due to requirements on redundancy and multiple-system versions to fulfill standards and constraints in different European countries. On good tracks, with the addition of 2 m noise barriers, pantographs may dominate the total noise level down to speeds as low as 200 km/h. Therefore, it is of great importance to implement low-noise pantographs on future high-speed EMU trains.

Development work on a new low-noise pantograph, ASP (Active Single arm Pantograph), is being carried out in a co-operative program between DB AG and Bombardier Transportation [16,17]. Testing on a first prototype of the ASP was carried out in the AUDI $6 \times 8\,m^2$ anechoic wind tunnel in Ingolstadt. The ASP was compared with the DSA 350 pantograph that is currently used on ICE 1 and 2 (see Fig. 9).

On the first ASP prototype, the pantograph head and knee were of a modified design but the foot region was unchanged. The foot region then dominated the noise emission, as clearly seen in

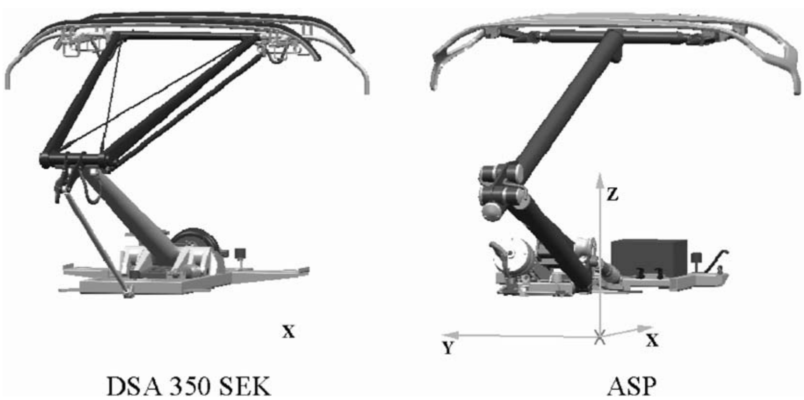

Fig. 9. DSA 350 SEK, ASP.

the results from the array measurements in Fig. 10. Noise generated around the foot would be somewhat lower on an actual EMU train than in the wind tunnel, due to the reduction in relative air velocity associated with growth of the boundary layer along the train. However, this area of the pantograph does, none-the-less, require noise control.

Test results from single microphone recordings at 4 m distance in the wind tunnel, shown in Fig. 11, indicate that a further reduction of about 8 dB(A) is realizable if modifications to the foot region are included, compared to the current DSA 350 SEK pantograph. In addition, it was found that the speed exponent of the ASP was reduced to 6.1, compared to a value of 7.2 for the DSA 350.

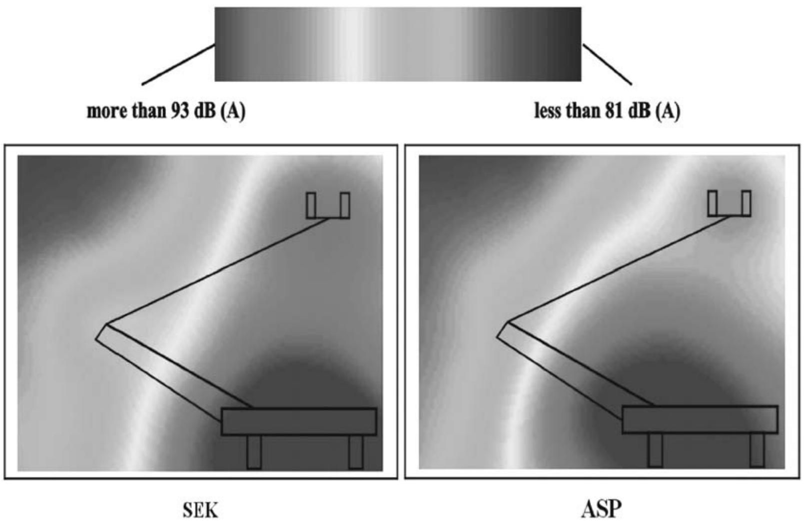

Fig. 10. Noise emission of the DSA 350 SEK and the ASP at 300 km/h [16].

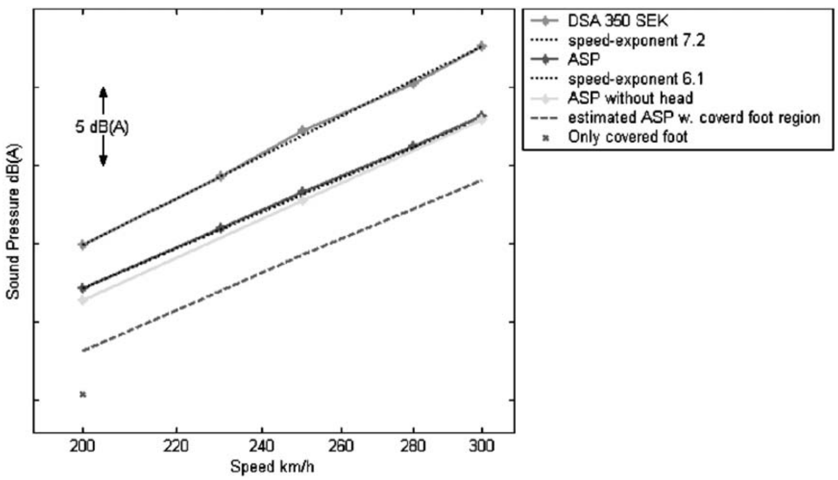

Fig. 11. A-weighted SPL for different pantograph configurations measured at 4 m distance in an anechoic wind tunnel.

5. Scenario for noise control of a future train

Pass-by noise levels from a future generic EMU train with conventional bogies and multiple pantographs are estimated in this exercise, with the following assumptions concerning applied noise control measures:

5.1. Rolling noise

- A further reduction in overall noise of 1 dB can be achieved, compared to Fig. 6, by:
  - introducing bogie shields, or
  - improving wheel damping further.
- Contributions from other mechanical sources at speeds above 150 km/h are negligible.
- Track quality is very good and pad stiffness is high and/or track absorbers are applied.

5.2. Aero-acoustic sources

- A further reduction in overall noise of 3 dB(A) can be achieved, compared to Fig. 6, by implementing:
  - bogie skirts,
  - low-noise pantographs with covers,
  - improved louvers, ventilators/fans, insulators and head shape of train.
- Ensure that overall surface of the train is smooth, with minimal contribution from steps and cavities or vortex shedding around extruding objects.
- Ensure that there is negligible contribution to the overall A-weighted level from inter-coach gaps, fairings, the wake or the turbulent boundary layer.

The above scenario is illustrated in Fig. 12, extrapolated for different speeds, showing the estimated contribution from wheel–rail and aero-acoustic sources. If all of the above noise control measures are implemented, it is believed that a level 2–3 dB lower than the present TSI

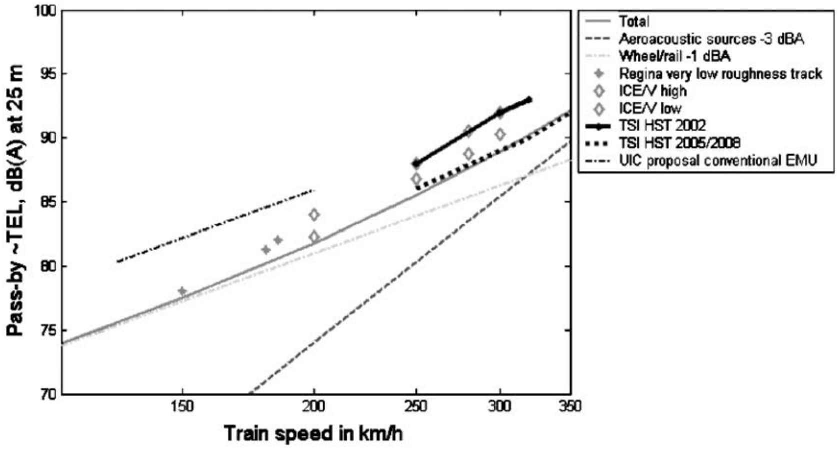

Fig. 12. Estimated pass-by noise levels from a future acoustically optimized EMU train.

requirements for high speed can be realized. It must be emphasized, however, that an introduction of all the measures described will add cost to the trains. Furthermore, reductions beyond this level would almost certainly be extremely difficult and expensive to achieve. Efforts and creativity must be focused on finding cost-efficient solutions, as well as solutions that are compatible with all other constraints when a platform for a new generation of train is developed.

6. Concluding remarks

The example described, which shows the relatively high noise emission levels for the Regina train when run on a track with medium roughness and soft pads, makes another important point clear: that is, it is not cost effective to develop quiet trains if they are not run on high-quality track which has low noise radiation. Specification of track conditions must be further developed in the measurement standards included in any noise legislation. The introduction of monitoring systems and other new technology for keeping rail and wheel roughness low, is crucially important in order to exploit fully the efforts being made to develop low-noise trains in the future. Trains, although designed for quiet operation can not compensate a poor track. An important consideration for railway vehicle suppliers to bear in mind when designing an optimal performance is that a vehicle will operate on tracks of different quality.

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