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NEW EXPERIMENTAL METHODS FOR AN IMPROVED CHARACTERISATION OF THE NOISE EMISSION LEVELS OF RAILWAY SYSTEMS

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The requirements to harmonize the limits for noise emission for the railway systems within Europe demands improvements of the existing joint measurement standards (ISO 3095 and CEN/TC 256). Recent research on rolling noise mechanisms or specific measurement techniques may help to meet the EC noise emission requirements. Some results from these studies have been taken into account in the CEN project standard document on noise emission of railbound vehicles. A review of the standardization approach is presented initially. Some measurement methods developed by SNCF, mainly of a diagnostic nature are then reviewed, including:

- — identification of track and vehicle noise contributions;
- — statistical approach to characterize the railway system noise emission values in operational conditions of maintenance;
- — quantification techniques with a vertical microphone array.

These methods, which may contribute to research work in that field, are reported, and results are presented.

1. INTRODUCTION

The European Commission Green Paper clearly specifies the need for uniform limits of noise emission from railway systems. Two complementary requirements are necessary to meet this goal:

- — the definition of indicators and their associated limits;
- — the developments of harmonized measurement methods, concerning either type testing, monitoring or diagnostic purposes.

Noise emission standards have been based on ISO 3095 since 1975. Considering developments in measurement techniques and new research since then, new proposals are presently being discussed within European standardization Committee (CEN TC 256). Techniques have been developed by SNCF (French National Railway Company) to assist these discussions, which may contribute to further improvement of the standards.

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2. ISO 3095

Today the existing standard ISO 3095 "Acoustics: measurement of noise emitted by railbound vehicles" defines indicators to represent the emitted noise level of a passing train from a single omnidirectional microphone, with the following main assumptions:

- rolling noise is the major noise contribution, which defines the location of the main sources as the wheel/rail interface region,
- the overall noise emission of a train unit is represented as a single omnidirectional source.

Several aeroacoustic source characterizations [1] have shown the importance of the aerodynamic noise contribution at higher speeds, especially due to sources located in the upper part of the train (i.e., pantograph or fans).

A scalar level value may therefore be insufficient to characterize such a source repartition. Thus, in order to specify noise emissions limits more precisely, discrimination of the acoustic sources in terms of their height or position may be necessary.

On the other hand, track conditions, which have been proved to have a major influence in the rolling noise excitation term, are not yet precisely defined. For the same train on several "standardized" tracks, the discrepancies might reach 5 dB(A) or more.

3. CEN PROJECT STANDARD DOCUMENT (Pr EN 3095)

Recent work on rolling noise generation mechanisms has been carried out [2] which allows a better description of both the rail surface quality (part of the excitation mechanism), and the balance between the contribution of wheel and track noise to the global sound emission level of the total railway system. Here the track contribution is often dominant, or at least not negligible.

On the other hand, the determination of a measurement method, including the rail contribution assessment, is essential in order to characterize rolling stock noise emission of the global train/track system.

In that respect, the main objective of the project to improve the CEN/TC256 standard "Measurement of external noise emitted by railbound vehicles" is the improvement and harmonization of measurement methods, especially for the track noise contribution.

The proposed methods will allow the rolling stock to be characterized at a test site and the noise emission of various vehicles on a particular track section to be compared. The reproducibility of the method is one of the essential requirements for type testing. The discrepancies between measured levels currently observed can be due both to variability of the wheel/rail roughness and track behaviour. Therefore the definition of an efficient method needs to focus on these two aspects.

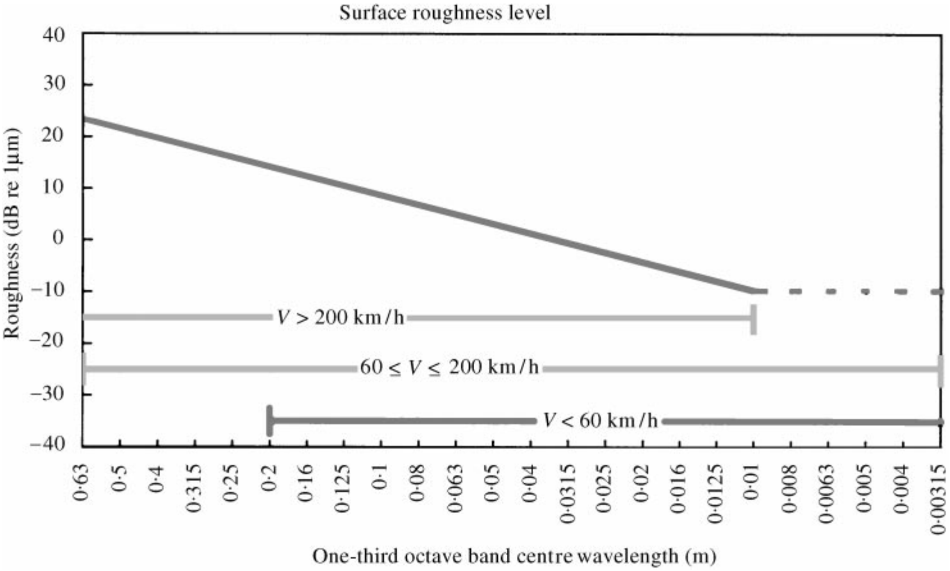

Figure 1. Rail roughness limit spectrum.

3.1. TRACK ROUGHNESS

The aim of the CEN/TC256 project is to provide a better characterization of rail roughness in real operational conditions. To ensure that the roughness will have a minimum effect on the overall noise emission, a limit spectrum for the rail head roughness has been determined (see Figure 1). The application of this criterion to real operational conditions is intended to limit the possible discrepancies, for a given rolling-stock series, due to the influence of track roughness variation on the total (track + rolling stock) emission level.

The values shown have been obtained from results on existing equipment. The application of these rail roughness conditions for two different tracks means that for given rolling stock equipped with disc-braked wheels, the overall change in rolling noise will be less than 4 dB. These conditions are considered to be precise enough for industrial concern.

This rail roughness criterion, based on a direct scanning measurement method, can be completed by an indirect method described later.

3.2. TRACK DYNAMIC PARAMETERS

Track dynamic parameters have a major influence on the noise contribution of the track. Recent research is not yet sufficient by developed to be used in a standardization process. The indicators and associated limits are still to be defined for a large sample of tracks available in Europe. Work initiated within the META-RAIL European research project indicates that there is still a lack of knowledge on this subject identifying a need for further work on track behaviour characterization, and definition of indicators and associated limit values.

4. METHODS PROPOSED BY SNCF

4.1. IDENTIFICATION METHOD OF TRACK AND WHEEL NOISE CONTRIBUTIONS

Some techniques developed by SNCF, which have been designed to take these aspects into account, and which may contribute to research work in that field, are described here.

One of these methods is based on the assumption that wheels and track have predominant noise emission in disjointed and identifiable frequency bands. For each of these frequency ranges, each acoustic source contribution is determined from the coherent spectrum, calculated from a sensor representing the acoustic source and a near-field microphone; in other words, the coherent part between the two sensors is the source contribution in the frequency range considered as far as the two sources are uncorrelated.

This method requires a sensor mounted on one wheel. When using a near-field microphone, it is considered that this microphone records the whole rail acoustic emission; that is to say, both the variability of the wheel/rail roughness and track behaviour.

In practice, the frequency range at which either main source (track or wheel) is predominant can be identified by an physical model such as the TWINS model developed at ERRI [3]. Roughness measurement is unnecessary for both wheel and rail whereas some dynamic parameters need still to be measured.

The method is applied either to the wheel or to the rail. In aiming for simplification the rail contribution can be considered using the following method.

4.1.1. *Track noise contribution*

The track noise contribution L_{ptr}, calculated from the ordinary coherence function between the near-field pressure level $p(t)$ and the signal of a sensor characteristic of the track noise emission $tr(t)$, is given over the frequency range f_1 to f_2 by

$$L_{p:tr_{[f_1,f_2]}} = \int_{f_1}^{f_2} S_{p:tr}\,\mathrm{d}f,$$

where $S_{p:tr}$ represents the contribution of the signal $tr(t)$ in the signal $p(t)$, defined by

$$S_{p:tr} = \gamma^2_{p:tr} S_{pp}$$

and S_{pp} is the autospectrum of $p(t)$.

The coherence function γ^2_{ptr} is given by

$$\gamma^2_{ptr} = \frac{|S_{ptr}|^2}{S_{pp}S_{trtr}}$$

where S_{trtr} is the autospectrum of $tr(t)$, and S_{ptr} is the crossspectrum between $p(t)$ and $tr(t)$.

4.1.2. *Contribution in the overall sound pressure levels*

In the frequency ranges where the track noise emission is predominant, the contribution L_{ptr} is estimated as follows:

$$L_{ptr} = \sum_{i,\, j} L_{p:tr_{[f_1,f_2]}}.$$

The wheel noise contribution is calculated using the same approach. The validation of this promising method is in progress, including the assessment of the discrepancies related to the preliminary hypothesis.

4.2. STATISTICAL APPROACH OF EMISSION VALUES

From the SNCF point of view, only a statistical approach, taking into account the operating conditions, is able to characterize the noise emission values and from this, the impact on the environment, as required by CEN standard developments. The method used by SNCF for its own network is presented here.

For a given type of rolling stock (TGV series, freight train, etc.), a specific on-site measurement campaign is arranged in order to determine the reference level called L_0. The sites are selected according to the surface conditions of the rail. Two techniques have been developed to assess the quality of the rail surface and its representativity of operating conditions.

- The first technique consists of an indirect scanning of rail roughness based on on-board acoustic measurements. The aim of this measurement system is to get a global assessment of the acoustic quality of the operating track of the network, depending on rail roughness range. This helps to define and optimize a maintenance policy for the rail surface, and to establish grinding operations.
- The second technique [4] uses displacement transducers for a direct scanning of roughnesses. This direct scanning allows a spectral representation of roughness levels. Data can be processed as typical inputs in the prediction models of rolling noise.

These two complementary techniques can be usefully associated in the selection process of outdoor noise measurement sites.

On the selected test site, a specific processing, taking into account the statistical distribution of passby equivalent levels for a relevant sample of the whole population of this type of train, can be performed.

These emission values are measured at a reference speed V_0, from a reference distance between the microphone and the axle of the circulated track D_0.

It has been proved that the statistical distribution law of equivalent passby levels is Gaussian, with a mean value L_m and a standard deviation σ.

Then for a number N of trainsets of the same class, we can write

$$\frac{1}{N}\sum_{i=1}^{N} 10^{0,1\,L_{Aeq,\,tp_i}(V_0,\,D_0)} \approx \int_{-\infty}^{+\infty} 10^{0,1\,L_{Aeq,\,tp}(x)}\, p(x)\,\mathrm{d}x,$$

where $p(L)$ is the density of probability of the $L_{Aeq,tp}$ probabilistic law.

Let us define L_0 as the reference equivalent noise level depending on the $L_{Aeq,tp}$ statistic distribution $p(L)$, for the reference conditions (V_0, D_0). Then

$$L_0 = 10\log\left[\int_{-\infty}^{+\infty} 10^{0,1\,L_{Aeq,\,tp}(x)}\, p(L)\,\mathrm{d}L\right].$$

Considering that L_0 can be written as $L_{Aeq,tp}(x) = L_m + [L_{Aeq,tp}(x) - L_m]$, and it is defined as $u = (L - L_m)/\sigma$, and $\mathrm{d}L = \sigma\,\mathrm{d}u$,

$$L_0 = L_m + 10\log\left[\int_{-\infty}^{+\infty} 10^{0.1u\sigma}\, p(L)\,\mathrm{d}L\right].$$

Finally, the reference value L_0, depending on the circulation speed and the distance from the centre of the circulated track, can be written in the following way:

$$L_0 = L_m + L_\sigma,$$

where L_0 is always superior to the estimated mean value L_m, and L_σ only depends on σ.

For instance, for a given site characterized by a sound pressure level of 115·5 dB(A), measured on-board a test vehicle, in the bogie region, the L_0 value of a TGV-A series was equal to 91·6 dB(A) at 300 km/h, at 25 m distance from the centre of the circulated track, with $L_m = 91{\cdot}4$ and $L_\sigma = 0{\cdot}2$.

4.3. VERTICAL ARRAY TECHNIQUES

It is now accepted that the sources of aerodynamical noise at high speed have an significant influence on the overall noise emission of a train, especially for those sources located in the upper part of the train. Further investigations have been carried out to assess their position, spectrum and level. The particular nature of these acoustic sources on a train [5] stimulated the development of a specific method, dealing with several problems such as accuracy, which takes into account the following factors:

— spatial and frequency resolution, and their adaptation to railway problems,
— Doppler effect consideration, at higher speeds,

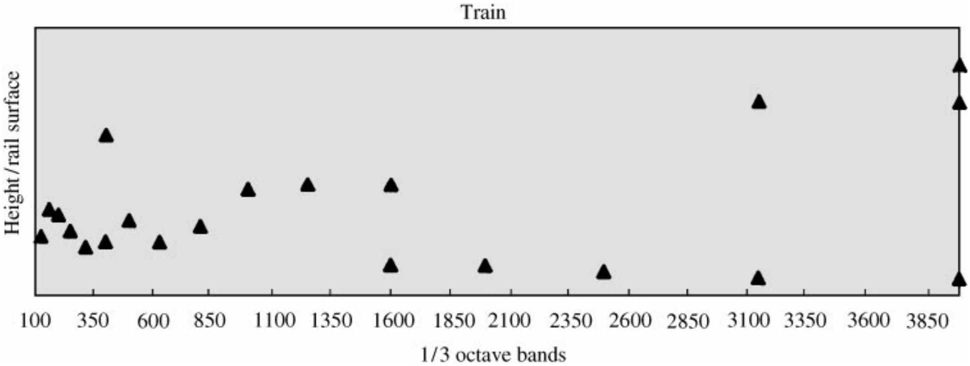

Figure 2. Height repartition of the main acoustic sources (1/3 octave bands) on a TGV-R running at 288 km/h.

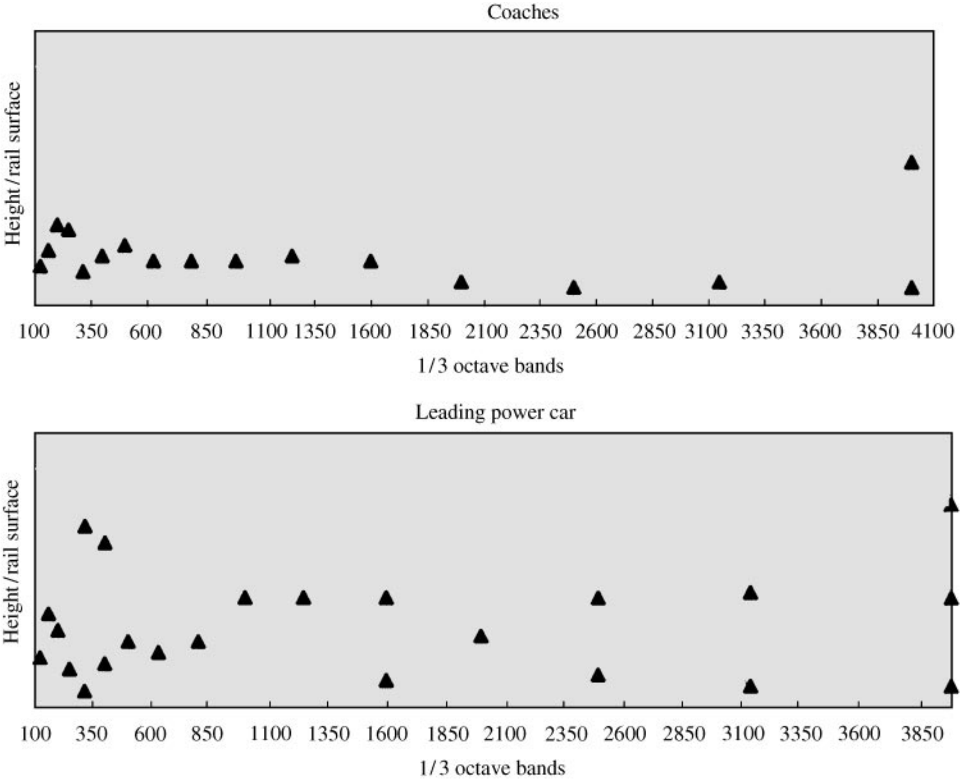

Figure 3. Height repartition of the main acoustic sources (1/3 octave bands) on the coaches and on the leading power car of a TGV-R running at 288 km/h.

— a short acquisition duration of the train pass by, as a constraint to cope with,
— compatibility with railway exploitation and safety requirements near the tracks.

A measuring tool has been developed to tackle these specific needs. Thus, considering that the acoustic array techniques [5] have proven their efficiency and robustness in attempting to locate and identify noise sources on a train, SNCF developed its own array measurement system.

The array, developed to deal with mono or bidimensional localizations, has been used in a vertical configuration, defined to cover the 1/3 octave bands with centre frequencies of 125–4000 Hz.

An example of the results obtained with this tool is given Figures 2 and 3. The separation of the energy is interesting to be considered, mainly in the higher frequency where the aerodynamic and rolling noise wheel contributions are clearly pointed out. The rail emission is less prominent than that from the wheel: the aerodynamic noise is liable to interfere.

For the leading power car, the rail and wheel contributions are in the frequencies associated with their classical emission frequency range.

The differences between the two graphs of Figure 3 show the need to distinguish the type of vehicle in order to define accurately the noise emission limits for trains. The possibility of identifying the height separation of the noise energy, according to the element of the train considered, should be available for any future standard.

5. CONCLUSION

The methods reviewed have outlined that research should contribute to improve the efficiency of the CEN project standard, even if some aspects, such as dynamic parameters, need further investigation.

The improvements of the standards and the measurements methods should answer, in the medium term, the EC requirements to harmonize the limits of the noise emission railways systems at a European level.

REFERENCES

1. C. Dine and J. Courtin 1997 *WCRR'97, Florence, Italy*. Characterisation of aerodynamic noise of a TGV with array measurements.
2. P. Fodiman 1996 *WCRR'96, Colorado Springs, USA*. Line test validation of low-noise railway components.
3. *ERRI Report C163/RP21* Railway rolling noise modelling. Description of the TWINS model and validation of the model vs experimental data.
4. J.-F. Cordier and P. Fodiman 1998 *6th International Workshop on Railway Noise, Îles des Embiez, France, Novembre* 1998. Experimental characterisation of wheel and rail roughness: an overview of methods used in France.
5. M. A. Pallas, K. P. Schmidz, B. Barsikow, P. Fodiman and G. Hölzl 1994 *WCRR'94, Paris, France, June* 1994. DEUFRAKO: localised sound sources on the high-speed vehicles ICE, TGV-A, and TR07.