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EXPERIMENTAL CHARACTERIZATION OF WHEEL AND RAIL SURFACE ROUGHNESS

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For several years, studies carried out in Europe have shown the need to consider wheel and rail surface roughness as a major excitation parameter in railway rolling noise. Measuring the rail roughness may be critical in the assessment of the noise created by the wheel/track system. It can be measured by means of two complementary methods:

- an indirect method based on the measurement of the axle box vibration or the noise level in the bogie region,
- a direct scanning of the surface defects with a displacement sensor.

The direct scanning method allows a spectral representation of roughness levels that can be strongly influenced by the applied data processing. It must include the removal of sharp spikes resulting from pits or spikes, which are not representative of the actual excitation of the wheel/rail system.

1. INTRODUCTION

The track–wheel interaction noise software (TWINS) model [1–2] explains the rolling noise generation mechanism by the uncorrelated presence on the wheel and the rail of surface microdefects which are often referred to as roughness. These defects introduce relative displacements between the wheel and rail surfaces. As a result, they produce vibrations in both the wheel and the track, which are converted into acoustic waves as they propagate into the environment.

The indirect method, which is presented in section 2, is based on on-board acoustic measurements in the underbogie region. This method provides a system of mapping the rolling noise level over the network. Results are used to implement an acoustic grinding policy on the SNCF high-speed network.

Section 3 deals with the direct scanning of surface roughnesses. Roughness data processing is often performed with a partial removal of surface defects [3, 4], which are not considered relevant for the effective excitation. On the other hand, no harmonized criterion for this phenomenon has yet been defined.

An original method of roughness signal pre-processing based on a pits and spikes removal is presented, the originality of which lies in the application of several

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correction schemes, depending on whether the defect to be treated is a pit or a spike. The results of this method, applied to two different wheel surfaces, and their respective influence when both pits and spikes removed are presented.

2. INDIRECT SCANNING METHOD

The indirect scanning of rail roughness is based on on-board acoustic measurements. The aim of this measurement system is to get a global assessment of the acoustic quality of the commercial track of the network, depending on rail roughness range. This helps in defining and optimizing a grinding policy.

The instrumention comprises two microphones, pointing to the opposite directions of rolling in the bogie area of the SNCF high-speed test coach MÉLUSINE (Figure 1). The on-board system allows the speed, the position along the track and the acoustic level for the microphone facing the direction of rolling to be recorded simultaneously. Figure 2 presents a typical result of the indirect method along a track where grinding was performed, it shows a range of about 8 dB(A) between ground section and rough section of this particular track. The short distance between the microphone and the rolling noise sources ensures that no contamination comes from external sources such as passing trains or acoustic barriers.

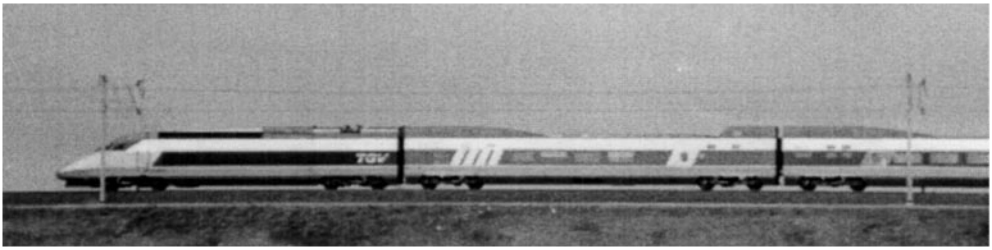

Figure 1. High-speed test coach used for indirect scanning of rail roughness.

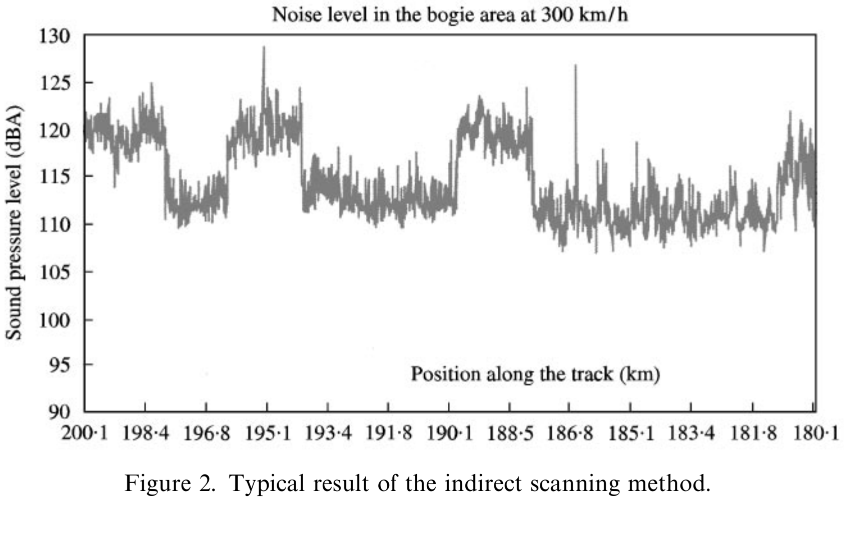

Figure 2. Typical result of the indirect scanning method.

An alternative to this acoustic measurement is the use of accelerometers on axle-boxes, but this has not so far been tested for this specific application. In any case, the indirect technique can be usefully associated with the direct scanning method in the process of selecting outdoor noise measurement sites.

3. DIRECT SCANNING METHOD—PRE-PROCESSING IN THE SPATIAL DOMAIN

The direct method allows a spectral representation of roughness levels which can be processed as typical inputs in the prediction models of rolling noise. Some precautions must be taken to ensure the accuracy of roughness signal analysis. In particular, the analysis of signals in the spatial domain must be performed before spectral analysis.

This method uses linear displacement transducer (LVDT) to record surface roughness data. A 5-step procedure is then adopted: pre-processing in the spatial domain, filtering, windowing, FFT analysis and conversion from narrow band to third octave band.

Roughness signals often contain sharp spikes relating to pits or spikes in the measurement surface. These defects can influence the roughness spectrum level, though they are not completely sensed by the wheel/rail contact. They often need to be considered as noise patterns, which must be corrected before spectral analysis.

3.1. FILLING OF "PITS" AND "SPIKES"

The origin of these defects and the way they are "read" by the wheel/rail contact are different irrespective of whether they are pits or spikes:

- Spikes are usually caused by particles with a short-term presence on the measurement surface. Hence, they must be removed according to some selection criteria.
- Pits can be related to squats or short cracks on the rolling surface. At the wheel/rail contact, the wheel follows the imposed displacement associated with the pit. The depth and width of the pit as well as also the wheel radius control the real amplitude of the relative displacement of the wheel.

The processing used aims to preserve only those parts of pits and spikes that are effectively "read" by the wheel/rail contact. In this respect, spikes are truncated when they exceed some limits, and each time the wheel cannot reach the bottom of the pit the signal is corrected.

The filling of pits and spikes involve two steps:

3.1.1. *Detection and removing of spikes*

- The top of a spike is detected by a change in the sign of the first derivative from positive to negative. Only the spikes with the maximum energy are deleted by setting limits on:
- the second derivative value,

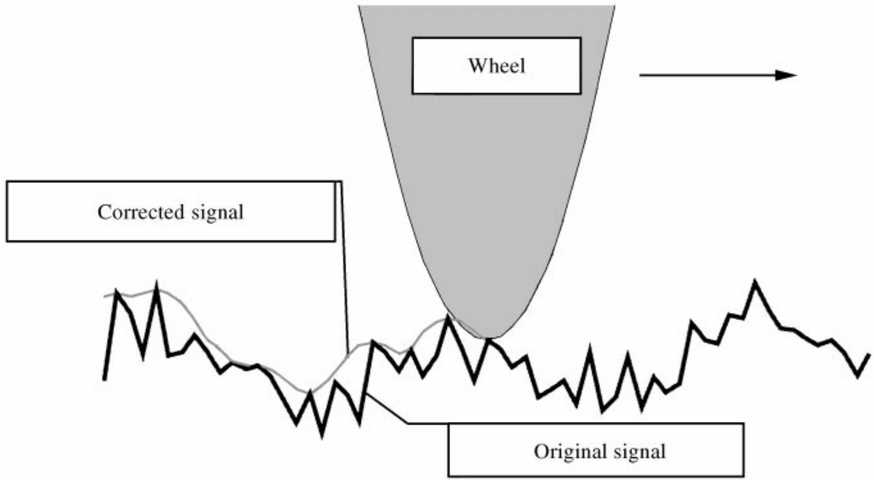

Figure 3. Pits correction.

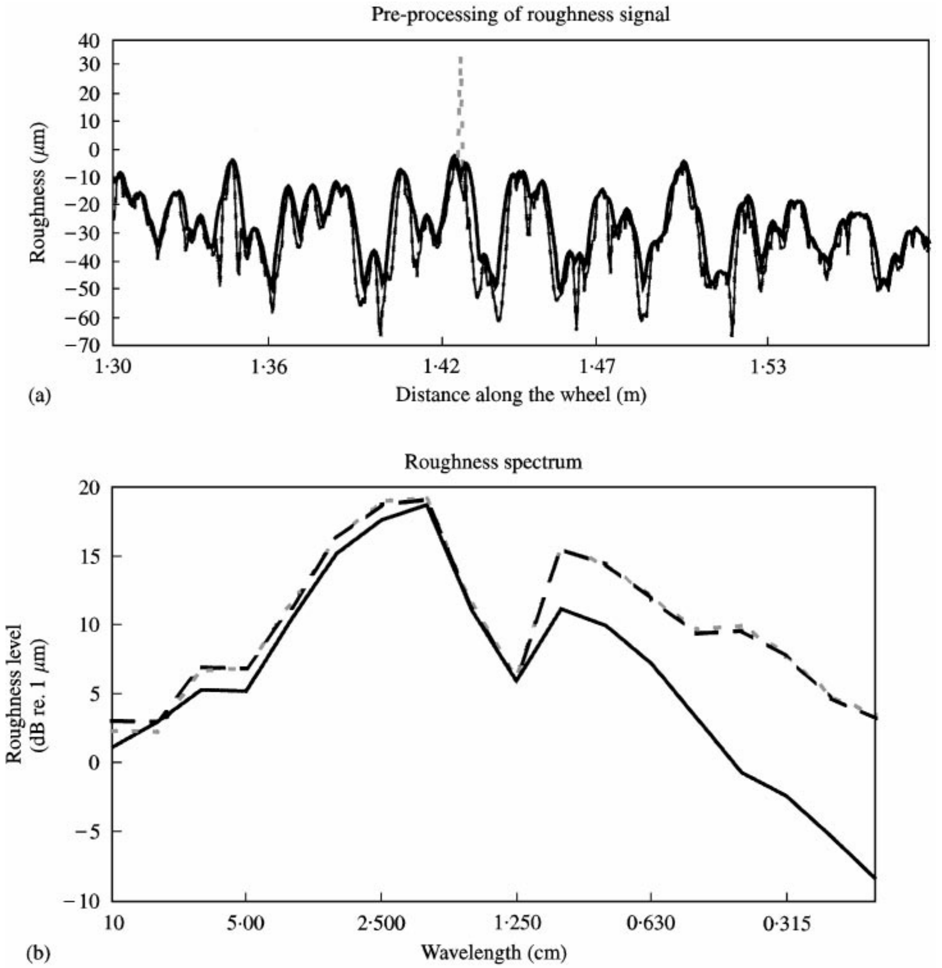

Figure 4. Wheel roughness with only few spikes. (a) Pre-processing of roughness signal. (b) Roughness spectrum. ---, original signal; – – –, spikes correction only; ——, spikes and pits correction.

• the local level of the signal, by comparing the signal with its envelope in the vicinity of the spike. This also gives the position of the edges of spikes.

Once the top and the edges of spikes are located, each spike is truncated by a linear interpolation between its edges.

3.1.2. *Filling of pits*

The pits filling (Figure 3) consists of the simulation of roughness signal scanning with a sensor having the same radius as the wheel. The resulting signal is the only part of the signal which is read by this sensor.

3.2. EFFECT OF DATA PRE-PROCESSING ON ROUGHNESS SPECTRA

The method has been applied to two different wheels representative of several surface maintenance states. The associated results are shown in Figures 4 and 5.

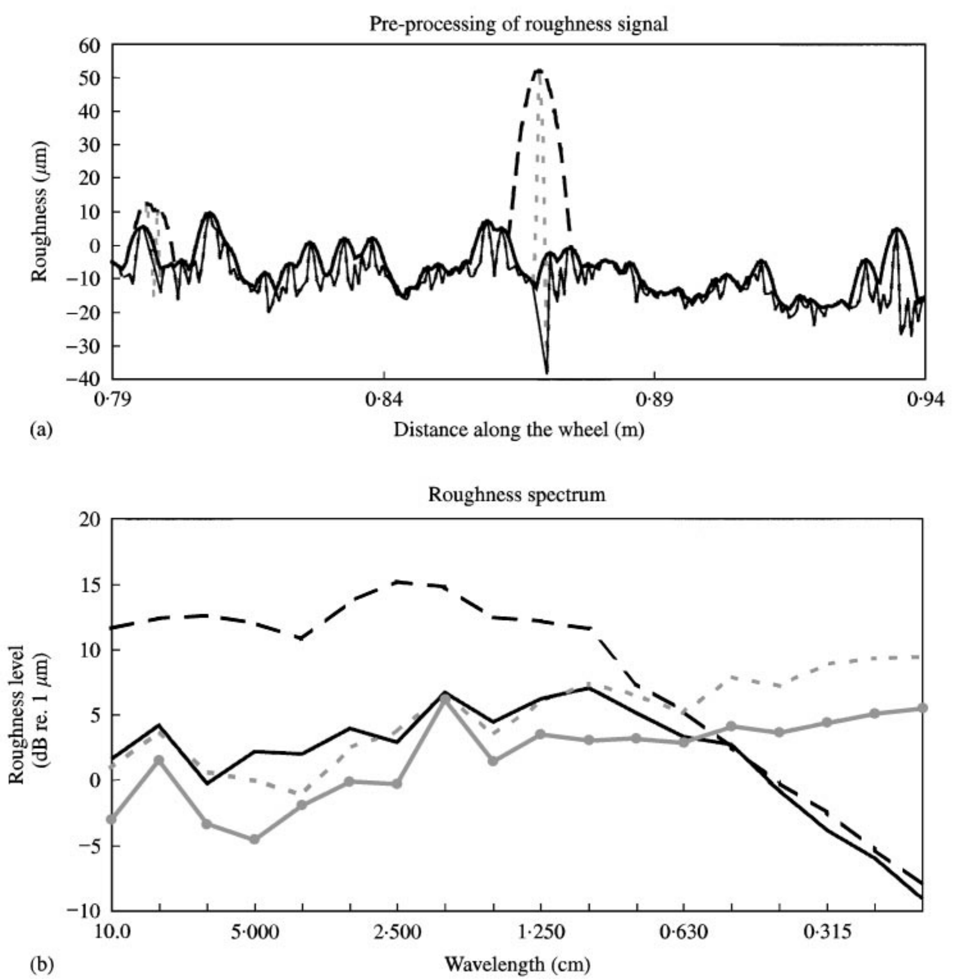

Figure 5. Wheel roughness including many spikes. (a) Pre-processing of roughness signal. (b) Roughness spectrum. - - - , original signal; —●—, spikes correction only; – – –, pits correction only; ——, spikes and pits correction.

The effect of pre-processing the algorithm is shown in Figure 4 in the case of one roughness signal including only few spikes. In this case, the removal of the spikes results in insignificant discrepancies on the roughness spectrum. The correction of pits gives large discrepancies, especially in the short wavelength domain (i.e., high-frequency domain).

Figure 5 shows the case of a wheel roughness signal with many spikes. Figure 5(a) indicates that the pits correction tends to widen the spikes. This lowers the spike energy in the short wavelength domain and increases the energy for large wavelength. Figure 5(b) shows the effect of spikes widening on the roughness spectrum: an increased level of up to 10 dB arises for large wavelengths. This clearly indicates that it is necessary to remove spikes before filling the pits.

4. CONCLUSION

Two complementary roughness scanning methods have been presented. The acoustic indirect method is used as a control tool for surface defects on rails. The direct scanning method is generally employed in specific rolling noise studies, including measurements and simulations.

An original method of processing roughness signals has been described and applied to two wheel surfaces, showing the possible discrepencies in the processed roughness level and the real influence of pits and spikes and their removal. This leads to some practical recommendations for roughness data processing.

As roughness is of major influence in noise generation, it highlights the need for harmonization of roughness processing techniques; this is currently being discussed in CEN TC 256 Working Group 3 on noise emission characterization.

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