'Noise Mapping' of a Railway Network: Validation and Use of a System Based on Measurement of Axlebox Vibration

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Summary

A series of tests have been undertaken on the French railway system to examine whether a commercially available system based on axlebox accelerometers offers a viable method of measuring amplitudes of railhead roughness that are significant for wheel/rail rolling noise. The HSRCA system that was tested gives repeatable measurements and a good estimate of acoustic roughness provided the measuring speed is similar to that at which the system is calibrated and the dynamic behaviour of the trackform is similar to that on which the system is calibrated.

The tests described below will demonstrate tentatively that the HSRCA offers a promising means of undertaking noise monitoring of a railway network.

1 Introduction

The issue of environmental noise in Europe is addressed specifically by the European Commission in Directive 2002/49/EC [1], which states amongst other things, the desirability of determining 'exposure to environmental noise through noise mapping, by methods of assessment common to the Member States'. To this end, the Research and Innovation Department of SNCF, the French national railway operator, is undertaking the LECAV project, which has the following objectives:

- to provide track roughness mapping of the entire French railway network as a critical step towards the 'noise mapping' anticipated by ref [1]
- to monitor acoustic performance of the track for a noise grinding policy.

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Longitudinal irregularities can be measured directly over short lengths of track, but this is impractical for measurement of a network of even modest size, let alone a system with thousands of kilometres of track. There are essentially two methods of indirect measurement of irregularities that offer the potential of undertaking such a survey of track roughness:

- measurement of noise on-board a vehicle (an example of which is the Schallmesswagen, or SMW, used by the German railway system, DB [2])
- indirect measurement of railhead irregularities using axlebox accelerometers, as proposed originally by Lewis and Richards [3] and used by several others since. Such a system is, for example, now used routinely by Banverket to provide corrugation information that is used amongst other things to plan rail grinding [4].

The principles underlying several techniques of measuring longitudinal irregularities, including axlebox accelerometers, are presented in ref [5], which discusses also the advantages and disadvantages of the different techniques.

The purpose of the first phase of the LECAV project was to examine the potential of measuring systems that are commercially available and that can be fitted to a conventional vehicle. To this end, a textbook example of a validation and testing exercise was undertaken on the French railway system in November 2009 using two sets of equipment: one based on noise measurement that is similar to the SMW system [2] and the HSRCA (High Speed Rail Corrugation Analyser), produced by RailMeasurement Ltd, which is based on axlebox accelerometers. Some results from an early version of the HSRCA, which was used for routine measurement of corrugation and welds on the Australian National railway system, are presented in ref [6]. This paper presents results that were obtained from the HSRCA system and discusses the potential of this system for routine measurement of longitudinal irregularities and acoustic roughness for the purpose of 'noise mapping' of a railway network.

2 HSRCA within LECAV Test Campaign

The HSRCA was initially developed to provide routine measurements of the severity of corrugation and discrete railhead irregularities (in particular, welds and joints), and thereby provide the information required to plan a campaign of weld straightening and rail grinding. The HSRCA supplied to Australian National was used for this purpose for many years [6].

The HSRCA samples axlebox accelerations on both rails simultaneously at a rate of 8000 samples per second, giving a measurement interval of approximately 4mm at the maximum recommended running speed of 120km/h. Vehicle speed and relative position are also measured using a digital tachometer signal supplied from the vehicle. The HSRCA software was designed to accommodate a longest wavelength component corresponding to a frequency of 5Hz and a shortest wavelength component corresponding to a frequency of 4000Hz.

The typical output of the system to date has been the severity of rail corrugation, shown as RMS amplitudes in 5 wavelength ranges as functions of distance, and ‘percentage exceedences’ of these RMS amplitudes, which are based on a value for each wavelength range that is selected by the user. The severity of discrete irregularities, if desired, is related to the maximum wheel/rail contact force, normalised to a specified speed (typically 80km/h).

For the LECAV measurement campaign, the HSRCA system was modified to provide one-third octave spectra of railhead roughness, which could be compared with limits such as that proposed in ISO 3095:2005 [7]. These spectra were calculated every 10m for both rails for 100m of track. The first phase of the test, described here, was designed to test, as simply as possible, the repeatability of the measuring system, the effect of measuring speed on reproducibility and the accuracy in order to assess whether the equipment was viable for noise mapping of the network. For the test, accelerometers were simply attached to studs that were fixed with epoxy adhesive to the axleboxes, with cables into the coach. All of the test equipment was transported to site by two people using public transport, fitted in less than a day and removed in only a few hours. The test coach formed part of a consist that was used for other test purposes (Figure 1).

Fig. 1. Consist for LECAV tests (colour figure online)

In order to assess repeatability, reproducibility and accuracy, the test consist ran from Paris to Orange in the south of France (day 1), three times around a test loop passing through Avignon (day 2), and then back to Paris (day 3). The consist ran over six sites, each of 100m length, which had been marked out in advance with transponders, to give an accurate indication on board the train of both ends of each site. A direct measurement of the roughness at all six sites had been made in advance using the Müller-BBM straight-edge instrument following the protocol in ref [7]. Two reference sites, on the northbound and southbound lines between Paris and Orange, had also been measured using the CAT (Corrugation Analysis Trolley). SNCF provided spectra for the two reference sites to calibrate the HSRCA. With the calibration thus made, the HSRCA was used to provide one-third octave spectra for the other test sites and test conditions. The test consist ran over reference sites 1 and 2 at 120km/h and 100km/h, respectively.

There were two other test sites on the northbound and southbound lines near Pierrelatte. On one of these sites, there were rail dampers, while there were no dampers on the rail at the adjacent site. For reasons of space, no results are presented for these sites.

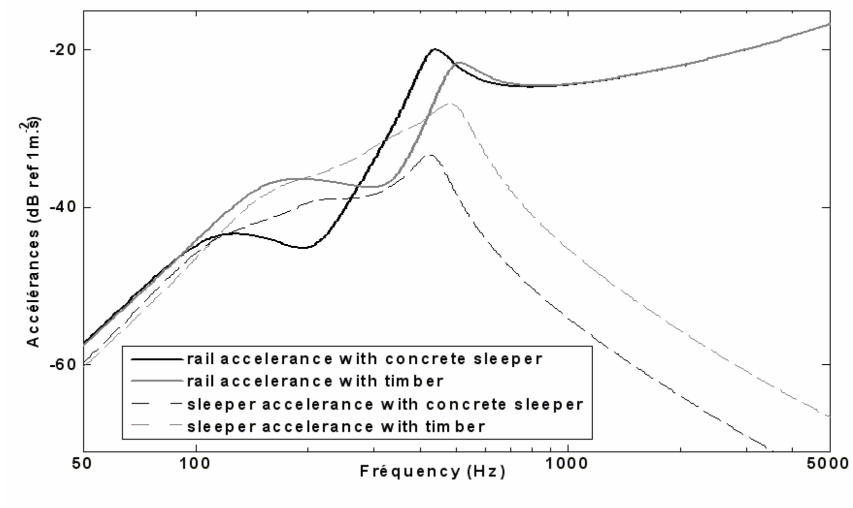


Fig. 2. Rail and sleeper accelerances, for concrete and wooden sleeper track. Track modelled with a Timoshenko beam continuously supported with a double stiffness layers: rail UIC60,ballast stiffness equal to 100MN/m^2, railpad stiffness equal to 300 MN/m^2, sleeper masses: concrete: 245kg timber: 96kg

The principle underlying equipment such as the HSRCA is that a transfer function relating axlebox acceleration to railhead irregularities is used to estimate irregularities from a direct measurement of axlebox accelerations. The accuracy of the estimate therefore depends critically upon the transfer function. The LECAV test was a particularly severe test of the influence of the transfer function, since the two reference sites and four test sites gave four significantly different sets of dynamic behaviour (even without the inevitable variation in ballast properties):

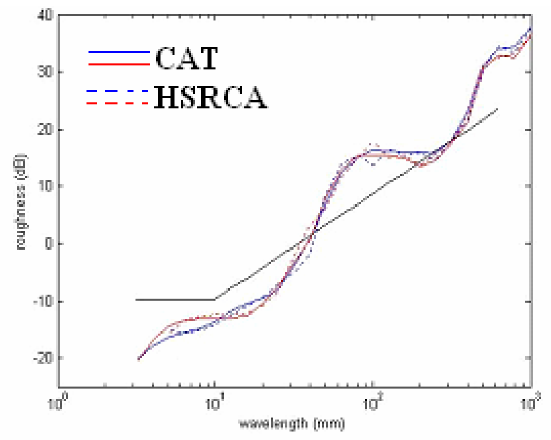
- timber sleepers, RN rail fastenings, 4.5mm railpad: reference site 1
- concrete sleepers, Nabla fastenings, 9mm railpad, no rail dampers: reference site 2, test sites 1 and 2
- concrete sleepers, Nabla fastenings, 9mm railpad, rail dampers: test site1
- concrete sleepers, RN fastenings, 4.5mm railpad:, test site 3

The sleeper alone significantly influences the transfer function for most of the frequency range of interest, i.e., 50-1500Hz, as illustrated in Figure 2. This shows the calculated transfer function between acceleration and contact force for a continuous track model in which the rail is modelled as a Timoshenko beam, the ballast and railpads as damped elastic layers and the sleepers as rigid bodies.

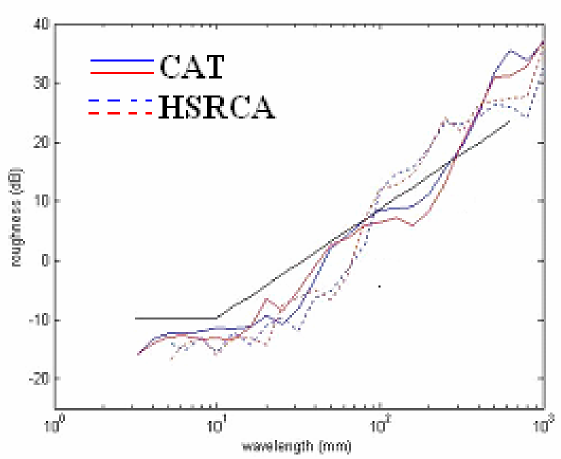
3 Test Results

3.1 Calibration of Equipment

Although in principle, the HSRCA can be calibrated using a single site for which ‘reference’ measurements are available, it is usually desirable to have at least two sites with extremes of corrugation, i.e., pronounced corrugation and very little



(a)



(b)

Fig. 3. Correlation of HSRCA and direct measurements of railhead roughness at reference sites (colour figure online)

corrugation. This helps to validate the HSRCA for measuring both large and small irregularities. In the present case, reference site 1 had moderate corrugation while reference site 2 was extremely smooth. However, since there was also a different trackform at the two sites (Section 2), the calibration was undertaken only for reference site 1 with reference site 2 used to check the results. The correlation of HSRCA and direct measurements for the two reference sites is shown in Figure 3. Since most of the measurements were made on test sites with concrete sleepers, it may have been better to use reference site 2 for calibration.

The principal difference between HSRCA and direct measurements of roughness at reference site 2 is for wavelengths of about 35-300mm. For the speed of 102km/h at this site, this corresponds to a frequency range of 100-800Hz. It is apparent from Figure 2 that the most likely cause of this difference is the influence on the transfer function of the different sleepers at the two reference sites.

3.2 Repeatability; Correlation of Direct and HSRCA Measurements

To assess repeatability of the system, three pass-bys were made at nominally the same speed of 120km/h over test site 3, between Miramas and Cavaillon (Figure 2). HSRCA and direct measurements of railhead roughness are shown in Figure 4.

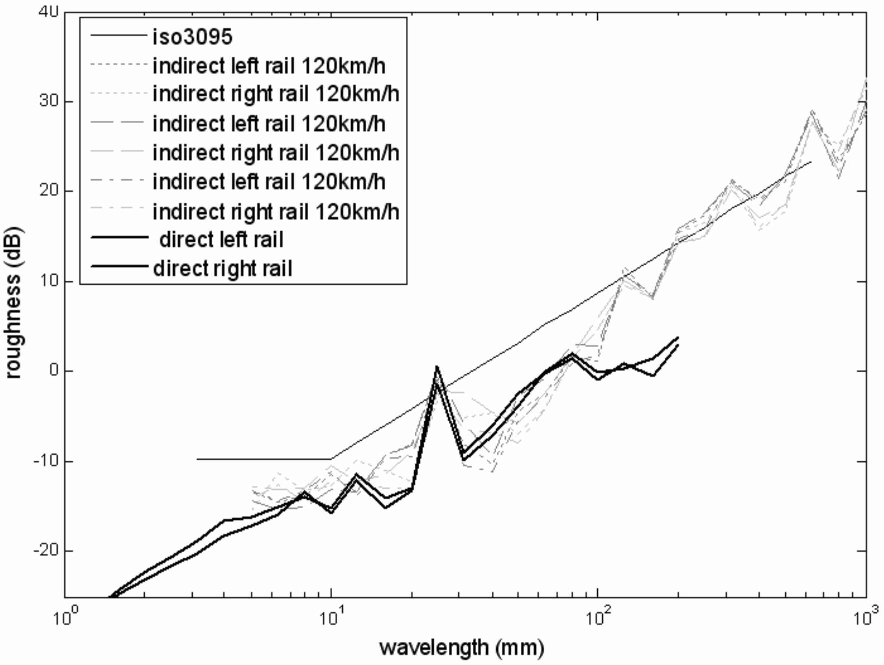


Fig. 4. Repeatability of measurements at 120km/h and comparison of HSRCA and direct measurements of railhead roughness, test site 3

Repeatability of the HSRCA measurements is very good throughout the wavelength range shown. The difference is typically no more than 3dB, with a maximum of 7dB in a few frequency bands around 30mm. The direct measurements (made with the MBBM instrument) are limited to 200mm wavelength. Correlation between HSRCA and the direct measurements is generally good at the shorter wavelengths, with the periodicity from grinding marks at 25mm shown particularly well. However, the HSRCA overestimates roughness at longer wavelengths. This is consistent with the different sleepers at test site 3 compared with those at the reference site used for calibration (Section 3.1).

3.3 Influence of Speed

To examine the effect of speed on the measurements, test runs were made at speeds of about 60km/h, 120km/h and 160km/h over test site 2, between Avignon and Miramas (Figure 2). HSRCA and direct measurements of railhead roughness are superposed in Figure 5.

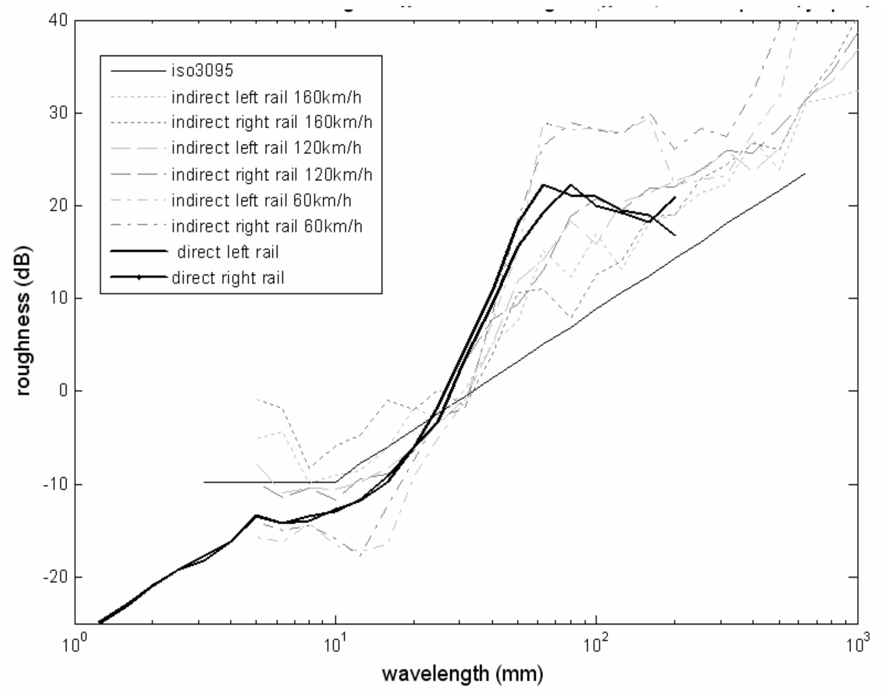


Fig. 5. Effect of speed on HSRCA measurements and comparison of HSRCA and direct measurements of railhead roughness, test site 2

There is reasonable correlation of measurements at different speeds in the 20-60mm wavelength range, with an average deviation of about 3dB. At other wavelengths, the measurements differ by as much as 20dB from one another depending on running speed. The difference between measurements made at

60km/h and 120km/h is greater than that between those made at 120km/h and 160km/h.

The HSRCA measurements at 120km/h again tend to underestimate roughness at wavelengths of 30-100mm and overestimate it at longer wavelengths, which is consistent with the influence of the different sleepers (Section 3.1). This site also had more resilient, 9mm railpads, which would be a further influence on this mid-frequency range.

4 Conclusions

The HSRCA corrugation-measuring system produced by RailMeasurement Ltd gives repeatable measurements of rail corrugation and acoustic roughness in the wavelength range 10-1000mm. The accuracy appears also to be satisfactory provided measurements are made at a similar speed to that at which the equipment is calibrated and that the dynamic behaviour of the trackform does not vary greatly from that on which the system is calibrated. Although the system is somewhat sensitive to both speed and dynamic behaviour of the trackform, there is nevertheless impressive correlation of direct and indirect measurements at a level of microns. This would be extremely difficult to obtain with any other technology that could measure at line speeds.

The effect of sensitivity to speed and dynamics of trackform could be alleviated in practice by attempting to run at a more constant speed than the almost threefold variation examined here and by calibration of the system for the predominant trackform on which it would be used. The possibility of having different calibrations for different trackforms could be examined.

The tests described here demonstrate tentatively that the HSRCA can be used to measure irregularities of an amplitude that is significant for acoustic work, and accordingly that it offers a promising means of undertaking noise monitoring of a railway network.

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