Rail Roughness Monitoring in the Netherlands

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Summary

Rail grinding is not a time-invariant noise mitigation measure. By reducing the rail roughness, the rolling noise will decrease, but since the rail roughness is not invariant, neither is the noise reduction that is achieved. In general, the rail roughness will again increase after grinding and consequently the rolling noise emission will increase. After a certain amount of time, the rail needs to be ground again to achieve a certain desired average noise reduction.

Regular monitoring of the rail roughness condition of the rail is necessary to keep track of the rail roughness and rolling noise emission changes over time. The rail roughness can measured with direct and indirect measurement methods. In the Netherlands, we have developed a monitoring method based on a combination of direct and indirect measurements. The direct measurements are done with commercially available instruments. For the indirect measurements we have developed a new system called ARRoW. In addition, a software program was developed that automatically combines the results from the direct and indirect measurements and delivers the roughness condition of a complete track.

The new monitoring method has been successfully used on the new high speed line (HSL-Zuid) that connects Amsterdam to Brussels and Paris and for conventional rail in a recent research project in the Dutch IPG (innovation) program. The technical details and some of the practical issues involved in the application of these methods will be discussed.

1 Introduction

Rail grinding is a noise mitigation measure that reduces the rolling noise of trains at the source. By reducing the rail roughness, the combined (wheel/rail) roughness is reduced. This decreases the excitation of rail and wheel vibrations, which leads to a lower sound radiation into the surroundings.

In the Netherlands, rail grinding for acoustic purposes has long remained in an experimental phase. This situation remained despite the fact that noise reduction by rail grinding is well-understood from theory and utilizable in practice. A problem is that the measure is only effective when the rolling stock using the track has relatively low wheel roughness. In the Netherlands in general, this is not the case because a large proportion of the rolling stock is (still) equipped with cast iron block brakes. Therefore, rail grinding was never put into practice on a large scale.

Recent developments in the Netherlands have renewed the interest for rail grinding. Firstly, a new high speed line has been constructed between Amsterdam and

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Belgian border, which connects to the European high speed network. On this line, rail grinding is viable and is indeed applied because this line is only used by modern (disc-braked) rolling stock with relatively low wheel roughness. Secondly, there is increasing attention to retrofit existing rolling stock having cast-iron block brakes with new block brake types (e.g. K, LL-blocks). This will eventually reduce the average wheel roughness on the existing conventional rolling stock. This will increase the possible effectiveness of rail grinding on the Dutch network.

But rail grinding itself is only half of the story that comes with rail grinding as a noise mitigation measure. We need measurement and monitoring methods to be able to put the measure in operation on a large scale. These methods are necessary to i) assess the actual noise reduction that is achieved due to rail grinding at a certain track, and ii) to monitor the development of the rail roughness and hence the noise reduction over a period of time. The results of the monitoring are used to schedule grinding maintenance to achieve a certain average noise reduction over a period of time.

In this article we will discuss the methods to measure and monitor the rail roughness, in the Netherlands and we will present the data processing framework to process the results of the monitoring measurements into a noise reduction that fits one-to-one with the current Dutch legislative framework and also with the future European noise impact calculation models [1].

As an illustration of the rail roughness monitoring methodology, we will use results from the monitoring program on the Dutch high-speed line (called “HSL-Zuid”). A general overview of the monitoring program can be found in [2]. We are currently investigating if the same methodology can be applied for conventional rail. This work is done in the framework of the Dutch IPG program.

2 Direct and Indirect Rail Roughness Measurement Principles

The monitoring method used on the HSL-Zuid and proposed for Dutch conventional rail consists of a combination of direct and indirect roughness measurements. This combination of measurement methods is a compromise between accuracy of the measurements and practical considerations.

In principle, direct measurement of the roughness profile would be sufficient for monitoring purposes because the direct measurement method delivers data that can be directly interpreted as a noise reduction. However, application of the direct method is not practicable for the HSL-Zuid (approx. 2 x 90 km track length) because many measurements are needed to obtain a representative roughness for the whole track. Moreover, these measurements need to be done while the track is out of service and the procedure is rather labour intensive.

To overcome the impracticality of the direct method for large track lengths, indirect roughness measurements can be done. In Germany this method is used to monitor the specially monitored track with the Sound Monitoring Coach). The indirect measurements consist of rolling noise measurements in the vicinity of the wheel-rail contact area. The idea behind this method is the fact that, for a given (low) wheel roughness and track system, there is a direct relationship between the rail roughness change and the change in of rolling noise. Thus, by measuring the noise variation, we know the roughness variation. However, due to several practical constraints, we believe that the indirect method is not as accurate absolutely as the direct method and it delivers noise level variations which cannot be directly translated into absolute changes of rolling noise emission level.

To overcome the impracticality of the direct method and the inaccuracy and relative nature of the indirect measurements, we combine the results of both methods to yield an accurate description of the rail roughness over large track lengths.

3 Combining Direct and Indirect Rail Roughness Measurements

The concept behind the combination of direct and indirect measurement method is that the indirect measurement results which are relative by nature can be made absolute. This is done by "calibrating" the indirect results on reference sections with additional direct roughness measurements. Or looking from the perspective of direct measurements, the direct measurement results on the reference sections are "smeared out" over the whole track by means of the indirect measurements results.

In the calculation methods for noise impact studies (e.g. [1][3]), there is a direct spectral relationship between combined wheel and rail roughness on the one hand, and noise emission change on the other hand:

$$\Delta L_{p,\text{grinding-average},i} = (L_{r,\text{track,grinding},i} \oplus L_{r,\text{vehicle},i}) - (L_{r,\text{track,average},i} \oplus L_{r,\text{vehicle},i}), \tag{1}$$

with $\Delta L_{p,\text{grinding-average}}$ as the noise emission change between ground and average track, $L_{r,\text{vehicle}}$ as the wheel roughness level, $L_{r,\text{track}}$ as the rail roughness level, $\oplus$ denoting energetic summation, and i denoting a certain frequency band. Since roughness is usually known as a function of wavelength λ and noise level difference is expressed as a function of frequency f, a spectral transformation $f_i = v/\lambda_i$ is made, which depends on vehicle speed v.

With equation (1), the direct measurement results, expressed as $L_{r,\text{track,grinding},i}$ can be translated into a change of the rolling noise level, given an assumed wheel and average rail network roughness. In the Netherlands, these assumptions are taken from the national noise impact calculation method.

With the indirect measurement method, we directly measure the rolling noise level, but not the noise level difference between ground and average track. However, since the variation of rolling noise results from rail roughness variation, we can still use equation (1) to express this variation. Assuming we know the noise spectrum difference between sections A and B of the same track, we can express this difference mathematically as

$$\left[\Delta L_{p,\text{A-B},i}\right]_{\text{indirect}} = (L_{r,\text{track,section A},i} \oplus L_{r,\text{vehicle},i}) - (L_{r,\text{track,section B},i} \oplus L_{r,\text{vehicle},i}). \tag{2}$$

We can then substitute this expression in equation (2) to yield

$$\Delta L_{p,\text{section A-average},i} = \left[L_{p,\text{A},i} - L_{p,\text{B},i}\right]_{\text{indirect}} + \left[\Delta L_{p,\text{section B-average},i}\right]_{\text{direct}}. \tag{3}$$

This equation gives a direct relationship between measured quantities and the noise level change on section A compared to average rail roughness. In practice, we use do not use just one but several reference sections to scale measured noise level difference spectra. This means that, instead of eqn. (3), we use a transformation based on the least square fit between the indirectly measured noise level differences and the noise level differences computed with roughness spectra obtained with the direct measurements at the reference sections. Mathematically this can be expressed as:

$$\Delta L_{p,\text{section A-average},i} = \left[L_{p,\text{A},i} \right]_{\text{indirect}} - \overline{H}_{\text{reference},i}\,, \tag{4}$$

with $\overline{H}_{\text{reference},i}$ as the average transformation function between computed grinding effect and measured noise level. If we have *M* reference sections (indicated with index *m*) then the average transformation function is defined as

$$\overline{H}_{\text{reference},i} = \frac{1}{M} \sum_{m=1}^{M} \left(\left[L_{p,\text{reference } m,i} \right]_{\text{indirect}} - \left[\Delta L_{p,\text{reference } m\text{-average},i} \right]_{\text{direct}} \right). \tag{5}$$

4 Measurement and Analysis Systems

4.1 Direct Roughness Measurement Systems

Direct roughness measurements have been done with the Müller-BBM 1200e, and its successor, and the ØDS TRM02 measurement devices. All measurements have been analysed according to the prEN 15610 standard [4]. Both systems are able to deliver results accurate enough to determine the noise reduction by grinding: although the systems deliver a different roughness spectrum, we found that the resulting A-weighted noise reduction is comparable within 0.2 dB. However, the systems are very different with respect to robustness, ergonomics and user-friendliness. A full comparison is beyond the scope of this article.

4.2 ARRoW Measurement System

The data acquisition part of this framework is called the ARRoW system. The system measures rolling noise, position and speed onboard a measurement vehicle. The system consists of 4 removable microphones (see Fig. 1) combined with a GPS receiver. The microphones are placed close to the wheel/rail interface to measure directly the rolling noise avoiding interfering reflections. The GPS receiver is used for position and speed information. A data acquisition system (Müller-BBM-VAS PAK mk II) is used to simultaneously register the (spectral) noise information and speed and position information. The system is completely self-supporting with respect to power.

For the ARRoW system we have to measure the sound at all four wheels of the measurement bogie. This quadruples the requirements for the data acquisition system at the benefit of i) being able to distinguish between left and right side rail of the track, and ii) introducing redundancy in the measurement chain which increases the robustness of the whole system.

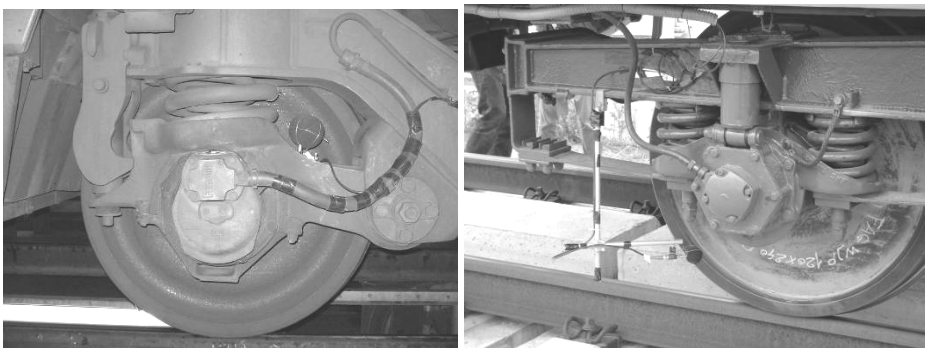

Fig. 1. ARRoW system on Thalys bogie (left) and on BAM rail measurement vehicle (right)

4.3 Data Processing and Analysis System

For the purpose of automatically processing and analyzing the measurement data, we have developed a dedicated software program that automatically couples the noise spectra, speed, and position information to the roughness spectra obtained with the direct measurements. As an end result, the program produces a complete overview of the roughness condition of the track as a function of the chainage. The analysis steps that are implemented in the software for the coupling of indirect and direct measurement results are described next.

1. Noise spectra for all four microphones are available as a function of time with a sampling interval of 0.05 s. This sampling interval results in a spatial resolution of about 2 m when measuring at a maximum speed of 160 km/h.
2. Position and speed information is available as a function of time with a sampling interval of 1 s.
3. Noise spectra and position/speed information are coupled to obtain the noise spectra as a function of chainage and speed alongside the track. For this step, the software requires a translation table from geographical coordinates to track chainage.
4. To take speed variation during the noise measurement into account, the noise spectra are scaled to a nominal measurement speed (v_{meas}) with a (frequency-dependent) logarithmic scaling according to the Dutch noise impact calculation model.
5. The noise spectra are averaged over a evaluation length (e.g. 20 m) to remove transient effects.
6. The noise level reductions $\left[\Delta L_{p,\text{reference-average},i}\right]_{\text{direct}}$ are computed for all reference sections, based on the average roughness-wavelength spectra for the reference sections. The wavelength to frequency transformation is based on the nominal measurement speed v_{meas}.
7. Compute the average transformation functions $\overline{H}_{\text{reference},i}$ using eqn. (5) for each microphone.
8. Translate the measured noise spectra for each microphone to noise reductions due to grinding applying eqn. (4). This gives the noise reduction spectrum due to grinding averaged over each small evaluation length interval.

9. If the nominal measurement speed is different from the target track speed, a frequency shift is applied to obtain the noise reduction spectrum at the target speed. This is in general required for high-speed lines, where we cannot measure at the target track speed.
10. A further averaging over left and right side microphones and over a certain chainage section length may be required as a final step. For the HSL-Zuid line e.g. the noise reduction effect due to grinding is evaluated over 1 km sections. This evaluation length and averaging process has been agreed upon with the environmental authorities.

A typical end result of this procedure is given in Fig. 2. For this particular case, the noise reduction is in compliance with the environmental requirements if the noise immission coefficient $C_{b,c}$ is below zero, which is the case over the whole track length in this example.

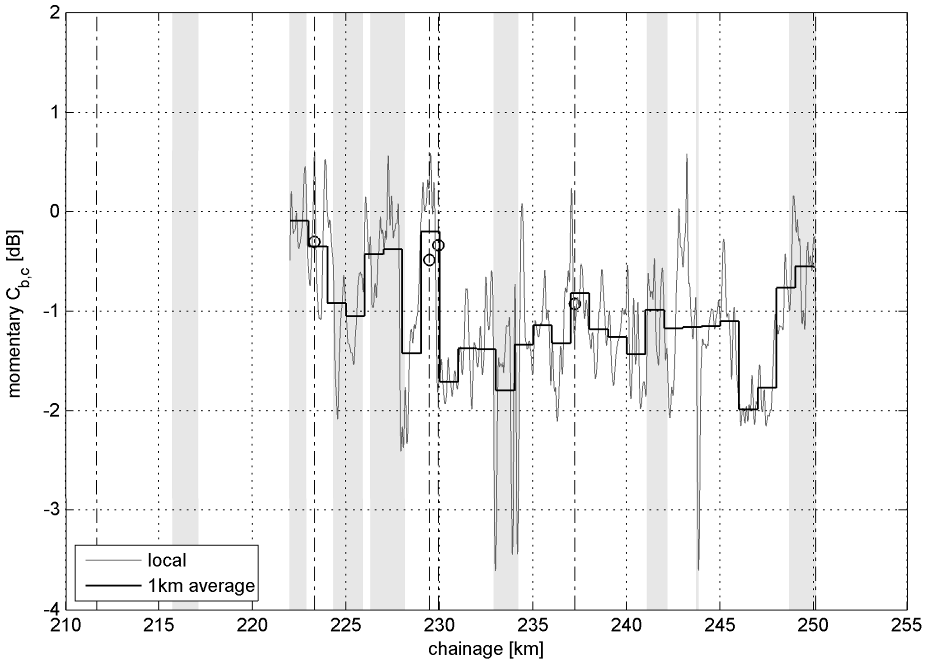

Fig. 2. A-weighted noise immission coefficient $C_{b,c}$ due to rail grinding measured at the HSL-Zuid track in the Netherlands, taken from [5]. The green line represents the small section average noise reduction, the black line represents the noise immission coefficient averaged over 1 km sections. The red circles represent the noise reductions computed from the direct rail roughness measurements.

5 Practical Experiences

At the moment we have applied the monitoring procedure described above a number of times on the HSL-Zuid line with different ARROW measurement setups (both with

Thalys and designated measurement vehicle measurements). During these measurements and the subsequent analyses we encountered a number of issues that need to be addressed to improve the applicability of the monitoring method for other (conventional) tracks:

- At high speed lines, the nominal measurement speed is different from the target track speed. This means that the wheels of the measurement vehicle might not be running on the running band that the high speed rolling stock uses. This issue arises especially in narrow high speed curves. We plan to use cameras to check if the wheel rolls over the correct running band.
- Another issue arises when we measure at a speed different from the target speed. Then we need a frequency shift for the noise reduction spectrum based on the quotient of the measurement and target speed. However, if the measurement speed is much lower than the target speed (which occurs in practice on high-speed lines) then the low-frequency part of the measured noise reduction spectrum determines the high speed noise reduction. This part can be distorted by interference from noise sources other than rolling noise, such as aerodynamic or traction noise which normally lie outside the frequency region of interest. This means that the measurement speed should not differ much from the target speed or that interferences need to be minimized.
- The rolling noise might change due to factors other than rail roughness, for instance change of superstructure type, reflections from platform sidewalls etc. If these are encountered in our measurements, we need to correct the measured rolling noise first before they are used in the monitoring analysis. We are still studying on methods how to do this.

Despite these issues, we believe that the current methodology is a sound basis to further develop a monitoring method to assess the noise reduction due to rail grinding.

Acknowledgements

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