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A TRAFFIC-DEPENDENT ACOUSTICAL GRINDING CRITERION

P. DINGS AND E. VERHEIJEN
NS Technisch Onderzoek, Postbus 8125, *NL* 3503 *RC Utrecht, The Netherlands*

AND

C. KOOTWIJK-DAMMAN
NS Railinfrabeheer, P.O. Box 2025, *NL* 3500 *HA Utrecht, The Netherlands*

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On most lines of the Dutch railway network, where a substantial amount of block-braked trains have rough wheels, the average wheel roughness dominates over the rail roughness. Therefore, reducing wheel roughness is top priority in the Netherlands. However, for the situations where rail roughness exceeds wheel roughness, this roughness can be lowered at acceptable cost. The high rail roughness is often due to rail corrugation which can be removed by grinding. A method has been developed to assess periodically the rail roughness on each railway line of the network, to compare it with the average wheel roughness for that line and to determine whether a noise reduction can be achieved by grinding the rail. Roughness measurements can be carried out with an instrumented coach. The two axle-boxes of a measurement wheelset are equipped with accelerometers. Together with the train speed and the right frequency filter, the accelerometer signal is used to produce a wavelength spectrum of the rail roughness. To determine the average wheel roughness on a given line, the so-called Acoustical Timetable can be used. This database comprises train types, train intensities and train speeds for each track section in the Netherlands. An average wheel roughness spectrum is known for each type of braking system. The number of trains of each type passing by on a certain track section determine the average roughness. Analysis of the data shows on which track sections the rail roughness exceeds the wheel roughness by a specified level difference. If this track section lies in a residential area, the decision can be made to grind this piece of track to reduce the noise production locally. Using this methodology, the noise production can be kept to a minimum, determined by the local average wheel roughness.

1. INTRODUCTION

In the past five years, thorough investigations have been carried out to assess wheel and rail roughness and noise in the Netherlands [1, 2].

These studies showed, firstly, a clear linear relation was found between wheel and rail roughness on the one hand and rolling noise on the other. If roughness is expressed in the right quantity, the energy sum of wheel and rail roughness can now be used to predict the rolling noise of a given train on a given piece of track. For this purpose a new quantity was proposed [3,4]: $L_{\lambda CA}$. This quantity is a single value indicator determined from the $\frac{1}{3}$ octave roughness spectrum.

Secondly, the inventory of roughness on the NS railway network and on the wheels of the trains running on the network showed that on most Dutch railway lines the average wheel roughness dominates. One reason for this effect is that NS still has a substantial amount of block-braked trains with rough wheels.

However, numerous occasions are found where rail roughness dominates. On some tracks, only disc-braked trains with smooth wheels are used, and throughout the network excessive rail roughness (such as rail corrugation) occasionally occurs. For these occasions, it might be worthwhile to reduce the rail roughness by grinding in order to reduce the rolling noise. It is important to be able to identify these locations on the network. Once these locations have been found, it is then important to estimate the amount of noise reduction which can be achieved.

In this paper, a method is proposed to measure the rail roughness on the entire network, to compare it with the wheel roughness of the trains for each line, and to select the track sections where rail grinding could bring a significant noise reduction.

2. DESCRIPTION OF THE METHOD

Figure 1 presents the layout of the method.

First, the rail roughness is measured by analyzing the axle-box vibrations from the NS Technisch Onderzoek (NSTO) test train. (This train measures several track properties of the entire NS network twice a year.) A filter H is used to transform the measured axle-box acceleration levels to $\frac{1}{3}$ octave roughness spectra. For this purpose, the test train speed, required for the filter, is measured. The average roughness spectra for each 25 m track section are stored in a database, for left and right rail separately, together with the exact position on the line. The Dutch Acoustical Timetable is used to determine the average wheel roughness on each

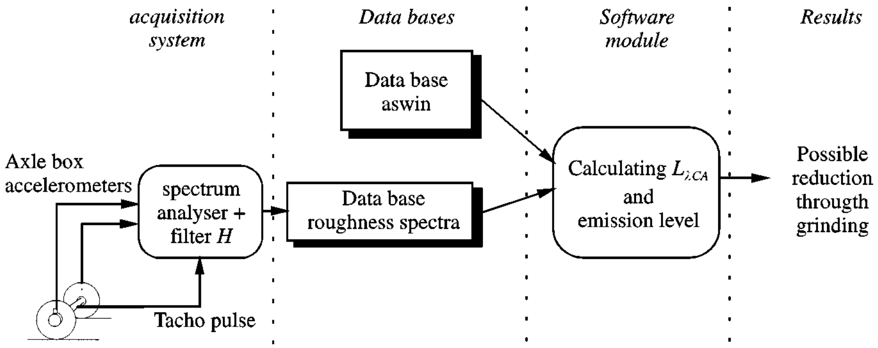

Figure 1. Lay-out of the complete system.

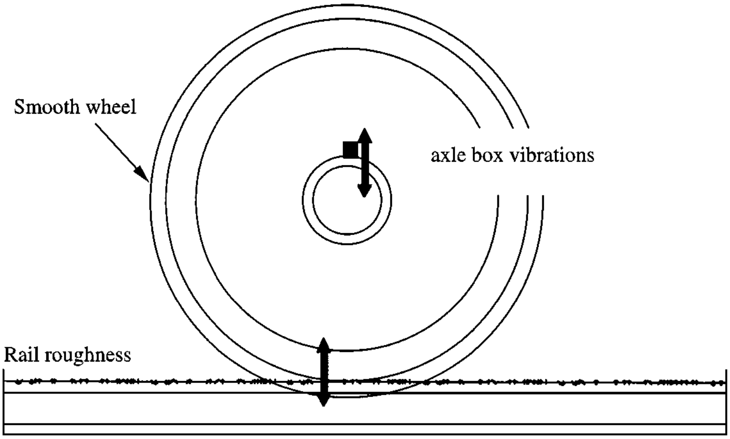

Figure 2. Principle of axle-box vibration system.

line, which depends on the mix of rolling stock and the train speeds per category. In this way, a comparison can be made between wheel and rail roughness for each track section on the network. If the rail roughness exceeds the wheel roughness by 5 dB(A) or more, track grinding is considered worthwhile. A map of the network can be made, indicating the track sections worth grinding and the total roughness reduction in dB(A) (equivalent to the noise reduction) achievable. Each step in this procedure is explained in more detail in the following sections.

3. MEASUREMENT AND ANALYSIS OF RAIL ROUGHNESS

3.1. AXLE BOX VIBRATIONS ON A TEST TRAIN

Accelerometers are mounted on both axle boxes of a non-tread-braked (and therefore smooth) wheelset of the NSTO test train (see Figure 2). Conventially, the r.m.s. amplitude of the signals of these accelerometers was determined in two broad wavelength intervals for maintenance purposes. However, as this system was not sufficiently accurate to give an acoustically relevant impression of the rail roughness, the system was modified. The signal is now fed into a spectrum analyzer to determine the $\frac{1}{3}$ octave acceleration spectrum. This spectrum is then transformed into a $\frac{1}{3}$ octave roughness wavelength spectrum, using the train speed and a filter H, described in the next section.

Calibration of the axle-box vibration system has been made on a test section with cross-sections with varying rail roughness. On these cross-sections, the precise rail roughness spectra were measured with two systems: RM1200E and RMF.

RM1200E is the Müller-BBM system using a 1·2 m straight edge with a tensile pickup moving along the edge, taking a height sample every 0·48 mm (see Figure 3). The analysis software transforms a 1·2 m longitudinal profile into a $\frac{1}{3}$ octave roughness spectrum from 0·1 to 10 cm.

The Vogel & Plötscher system RMF is used to determine the roughness in the wavelength range from 10 cm up to over 1 m. In this system, the longitudinal profile

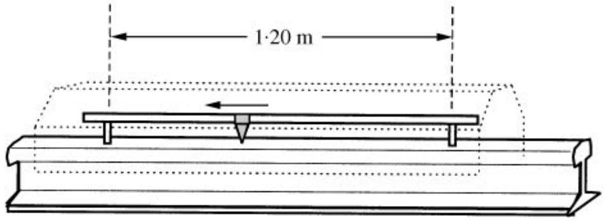

Figure 3. Principles of RM1200E.

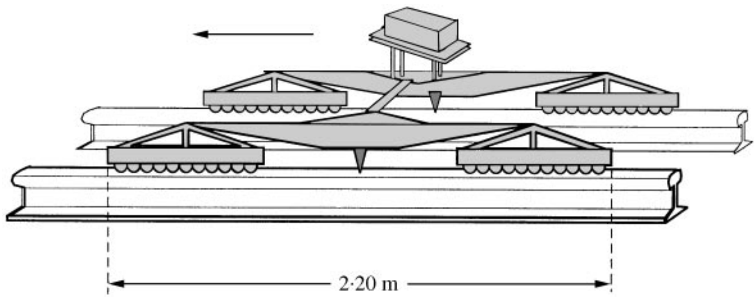

Figure 4. Principles of RMF.

is measured by a contact pick-up in the middle between two skates with small wheels with a base of 2·2 m (see Figure 4). The system is less accurate, but suitable for the measurement of roughness values over 10 dB in the lower wavelength range. The systems can be pushed along the track at walking speed, and therefore offers a cost-effective way of measuring track roughness.

3.2. ANALYSIS AND DETERMINATION OF TRANSFER FILTER H

Figure 5 shows the transfers from roughness levels on the rail to axle box vibrations. This transfer can be used to determine which filter to use to calculate rail roughness from measured axle box vibrations.

It is assumed tht the system is linear and rail roughness dominates wheel roughness: if the rail roughness determines the axle-box vibration level following a linear relationship, the inverse of this relation can be used to determine roughness from vibrations. In formulae:

if $$H = L_a - L_r,$$

then $$L_r = L_a - H,$$

or $$L_r = L_a + H^{-1}.$$

This principle was used and the filter H was determined by subtracting the acceleration spectra from the axle box and the roughness spectra from RM1200E

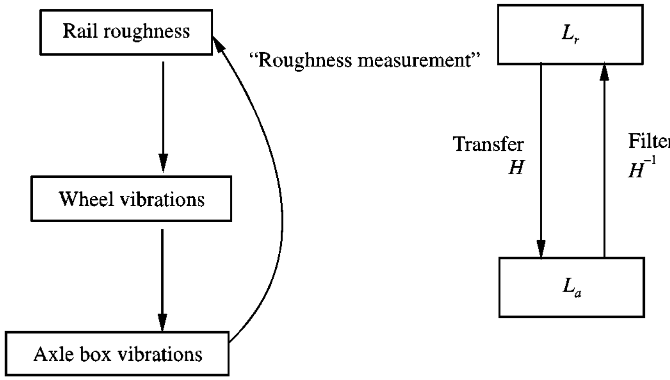

Figure 5. Chart of transfer from roughness to vibrations.

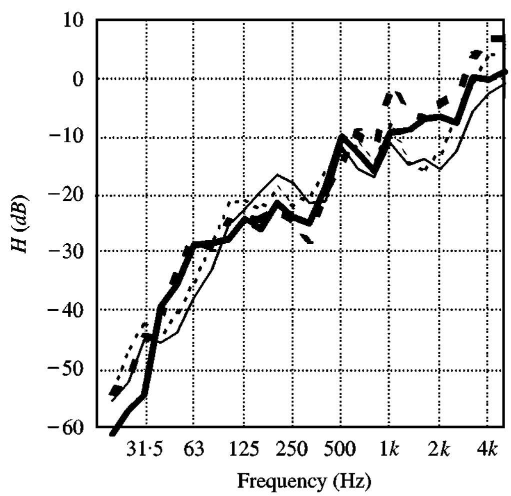

Figure 6. Transfer spectra for left and right measurement wheel at 60 and 120 km/h: ____, Left wheel, 60 km/h; ____, Left wheel, 120 km/h; . . . . ., Right wheel, 60 km/h; - - -, Right wheel, 120 km/h.

and RMF. This was done for the left and the right wheel of the NSTO test train separately and for two train speeds of 60 and 120 km/h. The resulting spectra for these cases are shown in Figure 6.

As the left and right wheel show little difference, the spectra will be averaged and the average will be used for both wheels. The speed dependence is more important. It is clear that the filter depends on the contact patch dimensions, which gives a different frequency effect at different speeds. The speed dependence has been modelled with TWINS and the same effect has been found there. The actual filter used on the train will have to be an interpolated filter between those of 60 and 120 km/h.

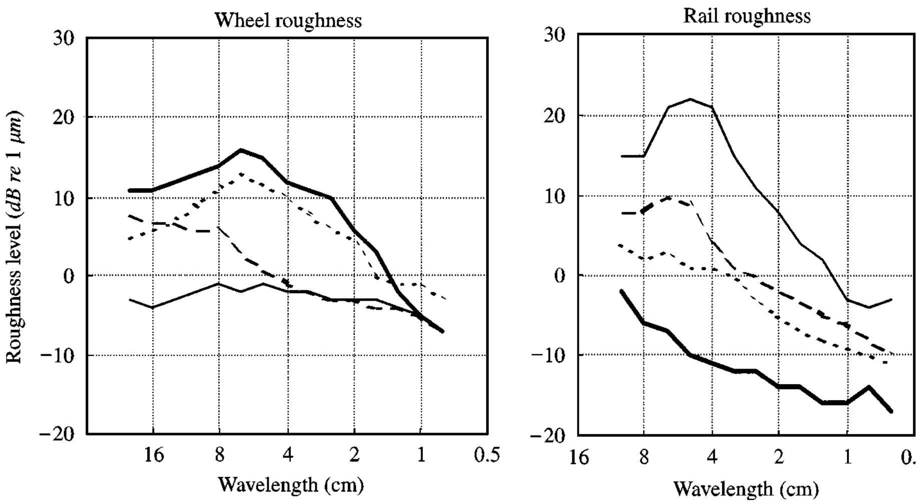

Figure 7. Typical wheel and rail roughness spectra: (a) ____, disc + add. sinter; - - - -, disc; . . . . . , cast iron; ____, disc + add cast iron. (b) ____, corrugated; - - - -, rough; . . . . . , average; ____, smooth.

4. AVERAGE WHEEL ROUGHNESS ON A RAILWAY LINE

4.1. WHEEL ROUGHNESS AND BRAKING SYSTEM

Figure 7 shows the wheel and rail roughness spectra typically found on Dutch trains and on the NS railway network. In the case of wheel roughness it was found that a principle reason for the variation is the braking system. Wheels that have a tread brake tend to become rough due to the block-tread interaction. However, for both of the braking systems, tread- and non-tread braked, the roughness level stabilizes after a few thousand kilometres, at a level determined by the brake system. The spectra presented in the left-hand graph are values for wheels at 200·000 km after reprofiling.

The spectra can be reduced to the two tables shown in Table 1 which gives the single-value indicator for roughness, $L_{\lambda CA}$. This indicator takes into account the fact that the roughness spectrum is tilted (differentiated) to get a velocity spectrum (λ), filtered by the contact patch (C) and A-weighted (A) to provide an indicator that gives a good correlation with A-weighted pass-by noise levels.

The spectra and the table show that for purely block-braked trains and for disc-braked trains with an additional cast-iron block brake the wheel roughness will dominate the rail roughness throughout the network, except on places with corrugation. The table also shows that on a line with mixed traffic the average rail is still smoother than the wheels, but that a rough rail or a corrugated rail might be worthwhile grinding.

The table also shows that the eight rolling stock categories presently found on Dutch railway track can be divided into four brake-type categories, and, eventually, in $L_{\lambda CA}$, into three roughness classes: I, disc braked; II, block braked; and III, disc braked with an additional cast-iron block brake. Class III is probably rarely seen in other countries, but the table shows that it is worthwhile retaining it as a separate class.

TABLE 1

$L_{\lambda CA}$ values for typical Dutch wheels and tracks

Wheel roughness ($L_{\lambda CA}$ in dB(A)) *Speed (km/h)*	40	60	80	100	140	200
Disc + additional sinter block	8	9	10	10	10	11
Disc braked: I	8	9	10	10	11	11
Block braked: II	14	16	17	18	18	19
Disc + additional cast-iron block: III	15	18	19	20	21	22
Rail roughness ($L_{\lambda CA}$ in dB(A)) *Speed (km/h)*	**40**	**60**	**80**	**100**	**140**	**200**
Corrugated rail	19	22	23	25	26	27
Rough rail	9	11	12	13	14	14
Average Dutch rail	5	7	8	9	10	10
Smooth rail	− 2	− 1	0	0	1	1
Freshly ground rail	3	6	7	8	10	12

4.2. THE ACOUSTICAL TIMETABLE

The Acoustical Timetable is a Dutch database, maintained by NSTO, with all acoustically relevant information about each part of the Dutch railway network. It contains infrastructure information such as superstructure type, number of tracks and presence of noise barriers on the one hand and traffic information on the other. For each line, the number and type of trains and the corresponding speeds can be found, as well as noise emission data per rolling stock type. This information is available for daytime, evening and nighttime separately, and for the years 1987, when the Railway Noise Decree (Bgs) of the Noise Nuisance Act came into force, 1994 and 2005. The database is to be used by anyone who has to make a noise impact study.

Knowing the number of cars per type and the corresponding speeds, this database enables the average wheel roughness level on a certain railway line to be calculated. This information can then be used to determine the difference between rail roughness and the average wheel roughness.

5. WHERE TO GRIND?

In the previous section a database was described which includes both local rail roughness for the entire network and the average wheel roughness of the wheels running over it. Using this database, the grinding criterion can be applied as follows.

First, check to determine whether, for one or more of the rolling stock categories the single-value rail roughness exceeds the single-value wheel roughness, both determined for the running speed of that stock type.

Check 1: for each stock category n, does $L_{\lambda CA,\,\text{rail, category}\,n} - L_{\lambda CA,\,\text{wheel, category}\,n} > 5$ dB(A)?

If this is the case for one or more categories, then a check is made to determine whether the total noise emission at this particular track section will be reduced if the rail roughness is brought down to a standard level after grinding.

Check 2: Does $E_{present\ situation} - E_{\text{after grinding}} > 5$ dB(A)?

Using GIS-oriented software such as the NSTO program GERANO, the database of possible noise reductions for each track section of the Dutch network can be visualized. The overall reduction per line can then, also in a GERANO module, be used to calculate the possible cost savings to be achieved if noise barriers are not then required. The economical comparison of the cost of grinding and of barrier installation will provide the decision about where to grind and where to leave the rail rough.

6. CONSIDERATIONS AND CONCLUSIONS

6.1. IMPLEMENTATION OF THE SYSTEM

At the present time, the system lay-out is known and it is ready for implementation and use. However, as no accurate information is available for the length of track that will have to be ground, no insight can yet be given on the economic benefit of the system. Implementation of the system as proposed depends on the potential economic benefit; the number of kilometres to be ground annually and at what cost versus the saving on barriers that would otherwise be installed.

A first estimate of the length of track with roughness well above the wheel roughness was made to overcome this impasse. A maximum length was found using the following procedure. The average roughness and its statistical standard deviation was used to determine a percentage of the total length of track with values more than 4 dB(A) higher than the average. This gave a length of 10% of the network, 500 km of track.

Using 7 euros as an average cost for grinding 1 m of track, the total cost for yearly grinding can be compared on a national scale to the cost savings for barriers that could be lower or not built at all. It is clear that for this purpose a more accurate estimation for the length of track to be ground is needed, and the only way to get this estimate is to do the work for the entire network.

However, it is clear that by using this methodology, the noise generation can be kept to a minimum, by determining the local average wheel roughness. The major advantage is that the rail roughness is not necessarily minimized, thereby saving money.

6.2. CHANGE THE PREDICTION METHOD?

Before this method can really can be used to save money on barriers, means will have to be found to incorporate smoother track into the Dutch calculation model.

At the moment, a national average for the rail roughness is inherently built in the model, because of the large number of sites that were used to carry out pass-by measurements to calibrate the model. At the present time, people living near a corrugated track are unfortunate. The fact has to be faced that an average is determined by higher and lower values. In principle there is only one way of dealing with the removal of the excessive roughness levels from the network thereby lowering the overall average by reduction of the emission formulae for each rolling stock type.

REFERENCES

1. P. C. Dings, and M. G. Dittrich 1996 *Journal of Sound and Vibration*. Roughness on Dutch railway wheels and rails. **193**, 103–112
2. P. Dings 1996 *Internoise* 1996. Liverpool. Rail corrugation: consequences for railway noise.
3. A. A. Van Lier and F. J. W. Biegstraaten 1997 *NSTO-Rapport* 9571011. The measurement, analysis and presentation of wheel and rail roughness.
4. P. Dings and A. A. Van Lier 1997 *World Congress on Rail Research, Florence*. Measurement and presentation of wheel and rail roughness.
5. L. Guccia *et al.* 1997 *World Congress on Rail Research, Florence*. High speed rolling noise. Design and validation of low noise components.
6. *DB Akustik Report* 47, *BT*511, April 1998 Determination of the sensitivity of the pass-by noise on rail roughness on standard ballasted track (in German).
7. *DB Akustik Report* 48, April 1998 Determination of a limit roughness curve after grinding for the especially monitored track (in German).
8. E. Verheijen 1998 *NSTO/97/9571182/1*. Development of roughness on the ERRI D185 test track Amersfoort-Baarn (in Dutch).