Procedure and applications of combined wheel/rail roughness measurement

M.G. Dittrich

TNO Science and Industry, Delft, The Netherlands, Email: michael.dittrich@tno.nl

Introduction

Wheel-rail roughness is known to be the main excitation source of railway rolling noise. Besides the already standardised method for direct roughness measurement, it is also possible to measure combined wheel-rail roughness from vertical railhead vibration during a train pass-by. This is a different quantity which has several applications. The measurement technique has significant practical benefits and has been in use for several years. There is currently still a need for measurement procedures for the following:

- Assessment of noise control measures under operational conditions (rail and wheel dampers, roughness control, track/wheel geometry, railpads, shielding)

- Separation techniques for track and vehicle contributions, and for separating rolling noise from other noise sources.

Combined wheel/rail roughness and associated transfer functions offer an efficient means for this purpose.

The method and procedures for the above applications are outlined here.

Outline of the method

Combined wheel-rail roughness $L_{r,tot}(\lambda)$ is the excitation quantity for wheel-rail rolling noise which is related to the directly measured surface roughness $L_{r,tot,dir}(\lambda)$of wheel and rail according to (see [1,2]):

$$L_{r,tot}(\lambda) = L_{r,tot,dir}(\lambda) + CF(\lambda) \qquad (1)$$

where λ = wavelength [m] ; CF = contact filter.

The combined roughness can be derived from the vertical railhead vibration according to

$$L_{r,tot}(f,v) = L_{veq}(f,v) + 10lg\left(\frac{D_s(f)}{8.68N_{ax}/l_{veh}}\right) - A_2(f) - 20lg(2\pi f) \qquad (2)$$

where

$L_{rtot}(f)$ = total effective roughness [dB re 1 micron]

$L_{veq}(f)$ = vertical rail vibration velocity [dB re 1 m/s^2] (over pass-by time)

$D_s(f)$ = vertical track decay rate [dB/m]
N_{ax} = number of axles
l_{veh} = vehicle or train length [m]
f = frequency [Hz]
v = train speed [m/s]
$A_2(f)$ = calculated or tabulated correction corresponding to the level difference between the combined roughness and the contact point [dB].

It should be noted that roughness can be expressed either in as a function of wavelength or as a frequency spectrum at a given train speed.

Some examples of measured combined roughness on a smooth track are shown in figure 1, for 3 groups of freight wagons of the same type with different brake block types (from [3]).

The vertical track decay rate can be obtained by analysing the signal rise and fall on either side of the vertical railhead vibration during a wheel pass-by. This gives quite reliable estimates, as shown in figure 2 (from [4]).

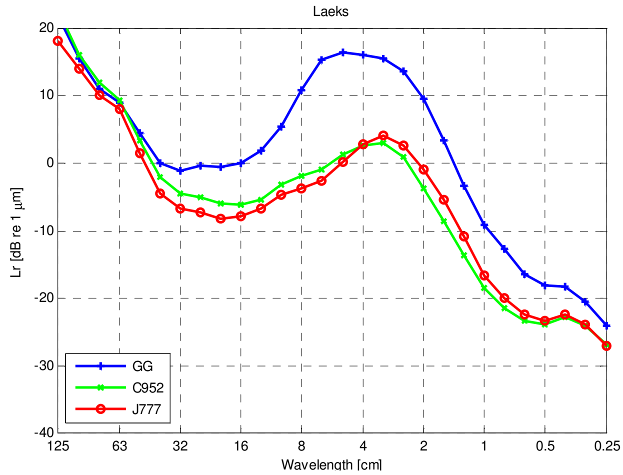

Figure 1: Measured combined roughness of freight wagon on TSI track – Cast iron, K and LL brake blocks

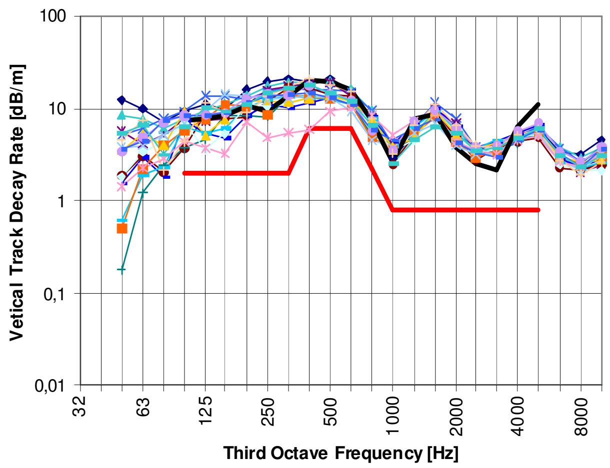

Figure 2: Measured vertical TDR determined with the PBA method for various pass-bys, compared with a curve obtained by the hammer impact method (___) and the TSI limit (___).

The pass-by sound pressure level at 7,5m distance can be given in terms of combined roughness, a transfer function which can also be split into a vehicle transfer function $L_{Hpr,nl,tr}$ and a track transfer function $L_{Hpr,nl,veh}$, and the axle density:

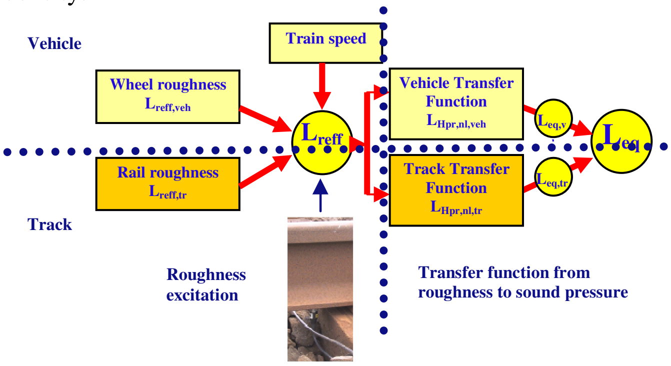

Figure 3: Schematic diagram of vehicle and track roughness and transfer functions

The above described method is implemented in the TNO Pass-by Analysis software (PBA) which has been frequently applied in recent years, for example in [3].

An illustration of curves for combined roughness and transfer functions are given in figure 4a-4c, taken from [5]. These are based on calculations and measurement, and illustrate value ranges for combined roughness and transfer functions which can be used for prediction purposes such as the Harmonoise/IMAGINE source model for railway rolling noise.

Pass-by sound pressure levels can be predicted by applying formulas (3) and (4). An example of a disc-braked vehicle at 80 km/h on smooth track is shown in figure 6, calculated from a combined roughness level and transfer functions for ballasted track with soft railpads, stiff railpads and stiff railpads with raildampers.

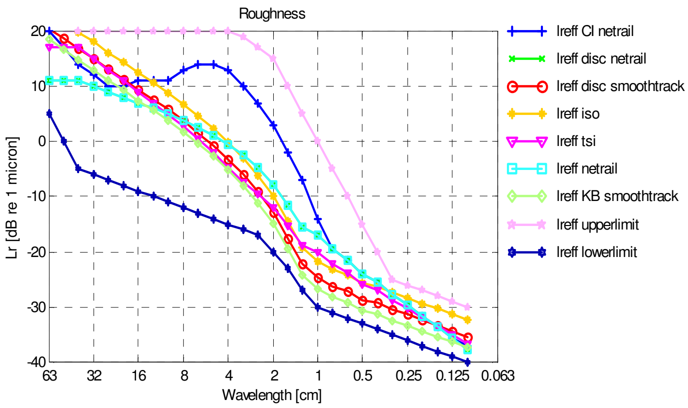

Figure 4a: Combined roughness levels for different combinations of wheel and rail roughness

$$L_{peq,roll,veh}(f) = L_{rtot}(f,v) + L_{Hpr,nl,veh}(f) + 10\ lg(N_{ax}/l_{veh}) \quad (3)$$

$$L_{peq,roll,track}(f) = L_{rtot}(f,v) + L_{Hpr,nl,tr}(f) + 10\ lg(N_{ax}/l_{veh}) \quad (4)$$

This is illustrated in a schematic diagram in figure 3.

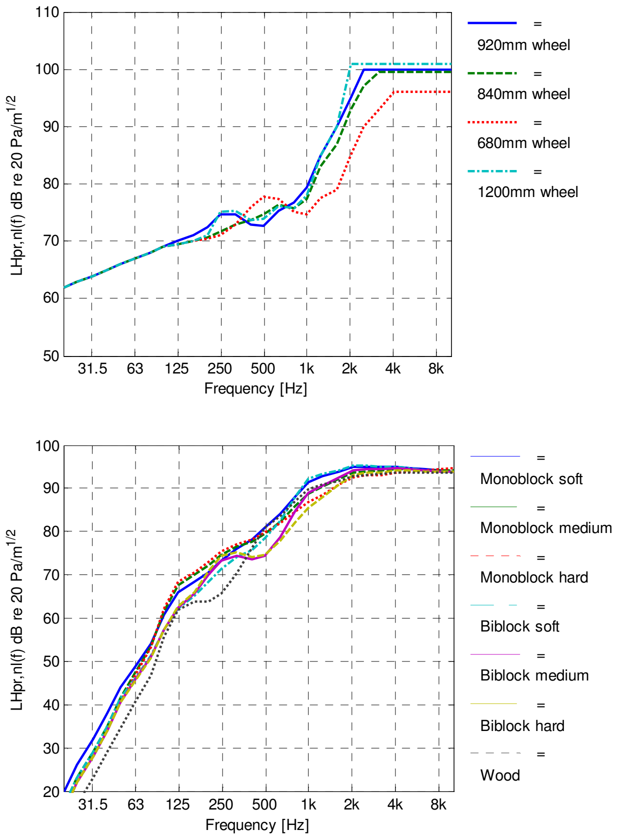

Figure 5: a) vehicle transfer functions for several wheel diameters b) track transfer functions for several sleeper and pad types

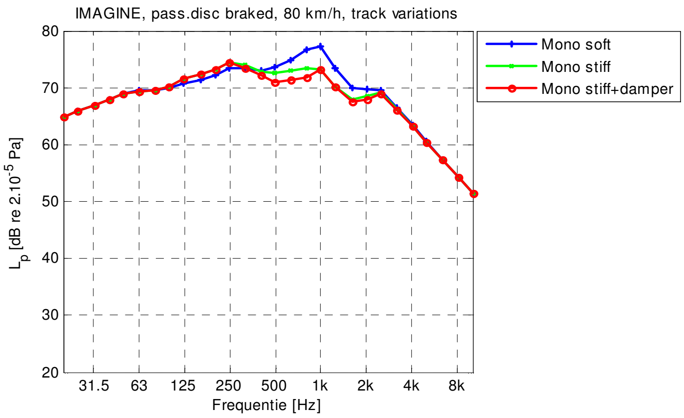

Figure 6: Pass-by sound pressure levels of a disc-braked vehicle at 80 km/h calculated from a combined roughness level and transfer functions for ballasted track with soft railpads, stiff railpads and stiff railpads with raildampers.

Procedures

With the above described method for determining combined roughness and transfer functions some procedures can be given that fulfill the needs described previously.

Combined roughness

Using the vertical railhead vibration time signal, firstly the vertical track decay rate can be determined by analyzing the slope of the vibration level around each wheel pass-by, in one third octave bands.
The combined roughness can easily be determined with formula (1) , with the equivalent vibration level over the whole pass-by and the decay rate.

Transfer function

The total transfer function can be determined from the combined roughness spectrum and the sound pressure spectrum for a given speed, and the axle density. The partial transfer functions for vehicle and track can be determined by analyzing pass-bys of different vehicles. In particular the track transfer function can be determined by using a vehicle with low sound radiation for example with small wheels.

Assessment of noise control measures

Noise control devices such as wheel dampers, rail dampers, railpads, but also different wheel and rail designs can be characterized by the transfer function. For this purpose it may often suffice to use the total transfer function, as the vehicle and the track tend to contribute in different frequency ranges.
The main benefit in using transfer functions is that they are roughness and speed independent and provide a characteristic spectrum that is transferrable to any situation. Especially when assessing noise reductions of 1-3 dB, the roughness needs to be eliminated as influence factor, which the transfer function does.

Assessment of wheel roughness

On a smooth track, combined roughness is a good alternative for direct wheel roughness measurement which can be costly and time consuming. Either whole trains, parts of trains or bogies can be assessed in this way during in service pass-bys.

Separation of other sources from rolling noise

Other sources such as traction or aerodynamic noise can be separated from rolling noise by comparing the total pass-by sound pressure level including all sources with the sound level derived from the combined roughness of the same pass-by and the transfer function from a pass-by at which rolling noise is dominant, e.g. around 80-100 km/h.

Separation of vehicle and track contributions

Vehicle and track noise contributions can be separated by applying the partial transfer functions (formulas 3-4), combining these with the combined roughness. Estimates for the track and vehicle transfer functions can be obtained by comparing transfer functions from multiple passbys or by using a quiet vehicle with low radiation

Conclusions

Combined roughness and transfer functions for rolling noise can be used for several applications for which there is a practical need. These include assessment of noise control devices, in service measurement of wheel roughness, separation of vehicle and track radiation, separation of other sources from rolling noise and several others. A practical measurement method and procedures are now available, suitable for standardisation.

References

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