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IN SITU DETERMINATION OF DYNAMIC TRACK PARAMETERS IN ORDER TO MODEL AND PREDICT NOISE AND VIBRATION REDUCING MEASURES.

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1 INTRODUCTION

In order to apply noise and vibration reducing measures on site it is necessary to know as correct as possible the dynamic track parameters. The only way to acquire these parameters is going onto the track, and to measure them as they are installed on site on a track that is loaded by a train, since material and ballast stiffness will change completely due to loading. Basic FEM models can be used to fine-tune these parameters for further analysis, while experimental soil excitation methods allow predicting and comparison of vibration levels on site.
Also data captured by the INFRABEL measurement car, such as rail surface corrugation, rail roughness spectra, as well as noise and vibration captured by fixed measurement posts will be included for evaluation and predicting noise and vibration emission.
Knowing these "on site" measured parameters will lead to a better prediction and estimation of costs involved with noise and vibration mitigation at INFRABEL.

Two types of measurements can be performed on site: direct and indirect measurements. Direct measurements are location specific and are very time consuming, while indirect measurements can be automated and can let us save a lot of time. After calibration with direct measurements, the indirect measurements will give us a good large scale approximation for e.g. a complete railway network.

2 MEASUREMENT OF DYNAMIC TRACK PARAMETERS

2.1 Direct methods

2.1.1 Description

A lot of methods for determining on a direct way the dynamic track parameters exist. Since the most important parameters that describe the noise source for rail traffic is the combined wheel-rail roughness, these parameters should be estimated not only as correct as possible, but also in as much locations as possible.

Rail roughness can be measured with commercial available devices as RM1200E (Müller-BBM),and others, while wheel roughness measurements are more difficult to perform in the field. The same measurement principles as used on rails can be applied. For rails roughness estimation standard procedures are well defined in EN15610 and ISO3095 norms. Some examples of measurements on train wheels as measured at Infrabel will be given later.

The Track decay rate is also a very interesting parameter to know in detail when talking about train noise. The measurement procedure is very well defined in the EN 15461 norm.

2.1.2 Practical examples

Some practical measurement examples will be given below.

2.1.2.1 RAIL ROUGHNESS MEASUREMENTS

In the following examples some measurements performed on the Infrabel network are shown. They show large differences in rail roughness on various locations. Three examples are given: Figure 2.1 shows a very smooth track that stays below the ISO3095 limit[1], Figure 2.2 shows the influence of grinding on the wheel roughness spectrum, while Figure 2.3 shows a significant rail corrugation wear on the railhead. These measurements require the track to be out of service and require time consuming measurement and processing procedures

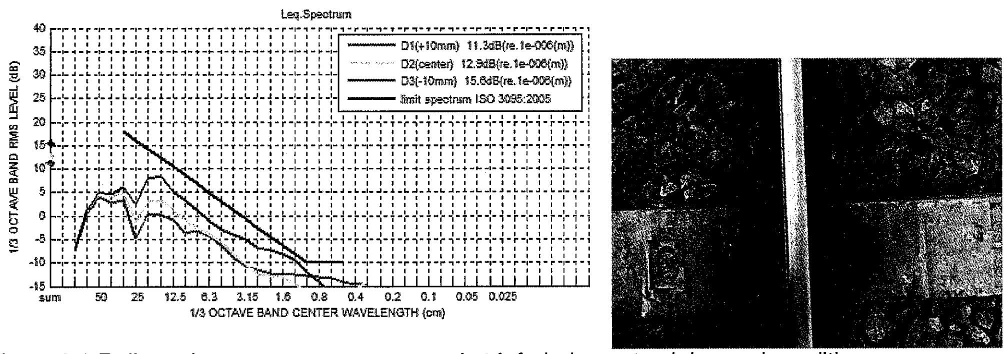


Figure 2.1 Rail roughness spectrum measured at Infrabel on a track in good condition.

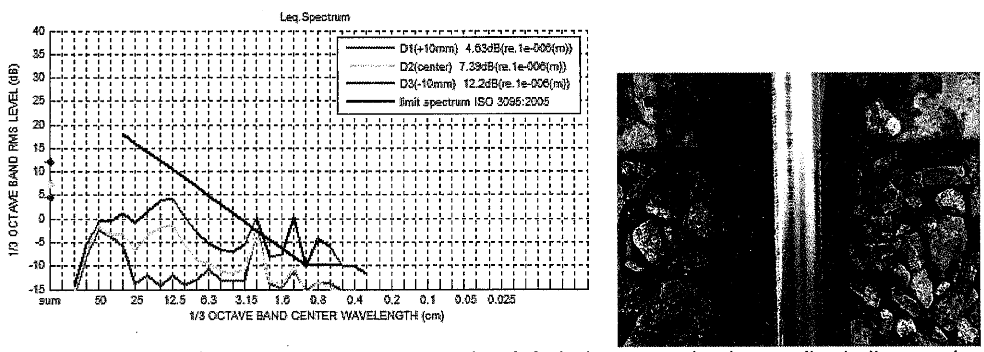


Figure 2.2 Rail roughness spectrum measured at Infrabel on a track where rail grinding marks are still visible

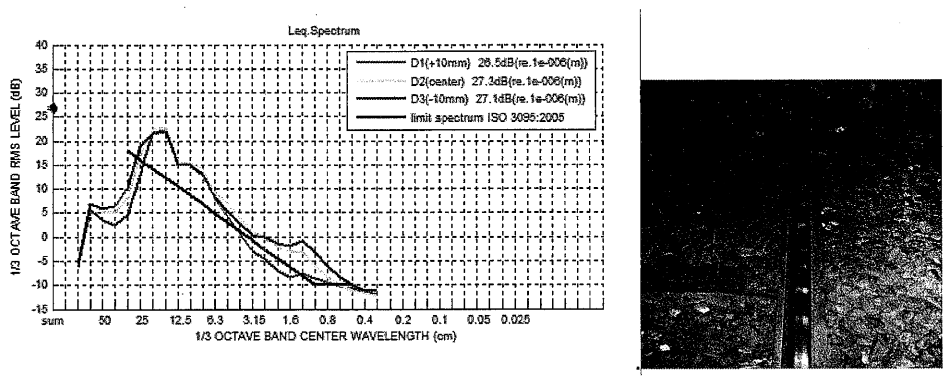


Figure 2.3 Rail roughness spectrum measured at Infrabel on a track where corrugation is present.

2.1.2.2 WHEEL ROUGHNESS MEASUREMENTS

The measurement principle is identical as used for measuring the rail roughness. Displacement sensors make contact with the wheel, which is lift up for free rotating, while an encoder is used for measuring the position of the running band.

Large differences on wheel roughness are seen for different positions on the running band. The outer side of the running band is more impacted by switches and shows a lot of pits. Before processing the signals these pits are removed by a specific selection-algorithm to avoid higher contribution in shorter wavelengths, which are not seen by the wheel-rail contact during running on standard straight track.

Figure 2.4 shows the presence of pits (blue) and data left for processing (red).
Figure 2.5 shows the measured wheel roughness spectra, sensors spaced 20mm from each other. Lowest values (rms values of 0dB or 1 μm) are found at the inner side of the wheel at the standard contact position between wheel and rail.

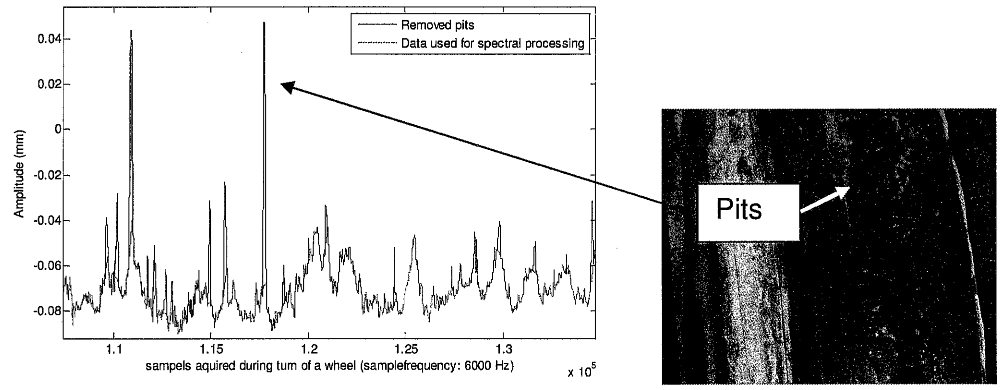


Figure 2.4 Presence of pits on the wheel running band

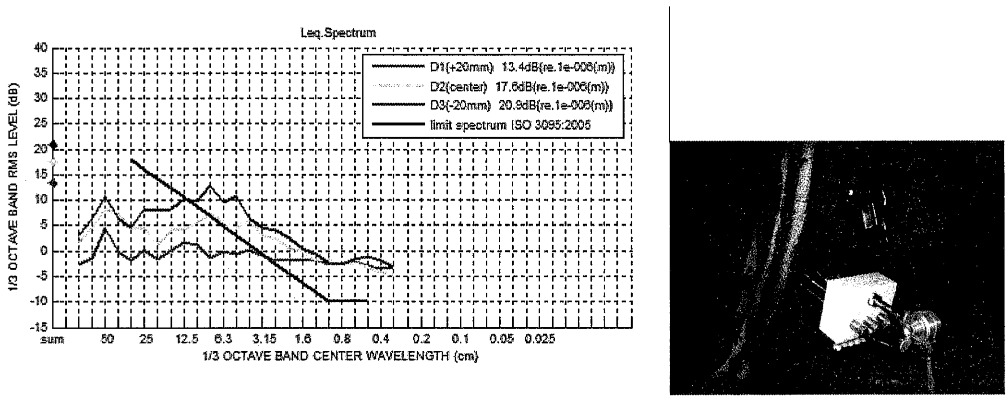
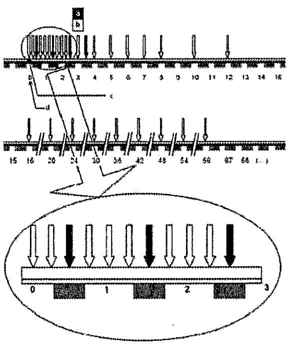


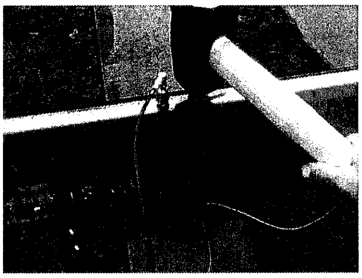
Figure 2.5 Measured wheel roughness spectrum on a train wheel.

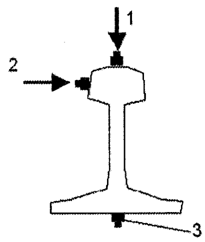
2.1.2.3 TRACK DECAY RATE MEASUREMENTS [2]

Figure 2.6 shows response and excitation locations to be used during the procedure as described in EN 15461 norm. Again this requires a track out of service and a lot of time: a few hundred hammer excitations are to be given.



Legende
a Hammerschlagimpuls auf die Schwelle
b Hammerschlagimpuls zwischen den Schwellen
c Position des Beschleunigungsaufnehmers
d Index des Schwellenzwischenraums





Legende
1 $F_{vertikal}$
2 $F_{lateral}$
3 Beschleunigungsaufnehmer

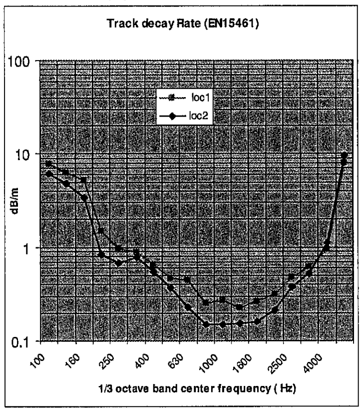


Figure 2.6: response and excitation locations during track decay measurements

Figure 2.7: Typical track decay rate results as measured on a standard track at Infrabel

2.1.2.4 DYNAMIC STIFFNESS OF THE TRACK

In order to be able to model a track by FEM we need to have an idea about the dynamic stiffness to be used in these models. Therefore a very simple impedance measurement can be performed, with and without a train that is positioned on the track. A typical transfer function as measured on a track which consist of M41 concrete sleepers and standard UIC60 Rail is shown in figure 2.8.
Three resonant frequencies are direct visual: Fpp (Pin-Pin frequency determined by the type of rail), Fr (Rail on the rail pad) and Fs (resonance of the complete track).

A simple FEM was used to verify these frequencies. An acceptable correlation between measurements and model was found.

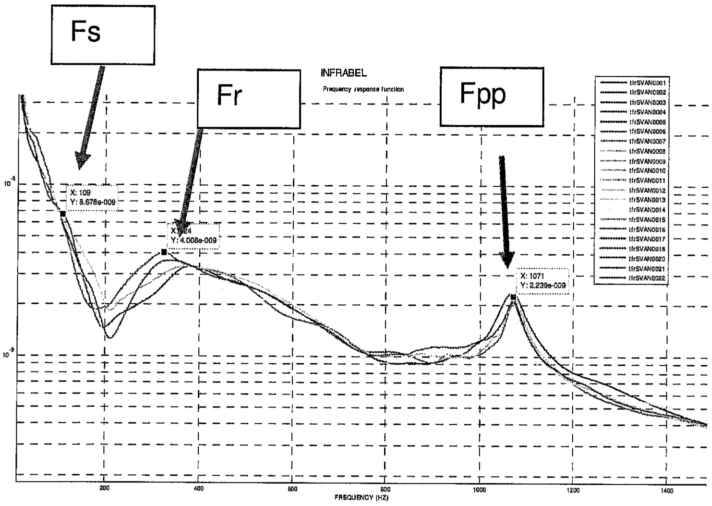


Figure 2.8 Transfer function (displacement/force) as function of frequency for a track with various types of rail pads

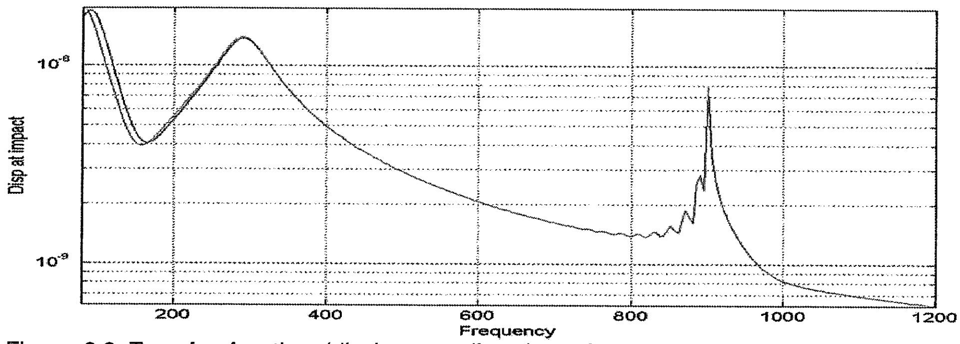


Figure 2.9 Transfer function (displacement/force) as function of frequency calculated by FEM modelling

2.3 Indirect methods

2.3.1 Description of methods

As seen above the direct methods are very time consuming and require in most cases that the track is taken out of service. To avoid these disadvantages we try to use indirect measurement techniques to gather track parameters as wheel roughness, rail roughness and track decay rate. Some examples are explained below.

2.3.2 Practical examples

2.3.2.1 PASS-BY ANALYSIS SOFTWARE (TNO)[3]

A very handy tool to determine indirectly important parameters as wheel roughness, rail roughness and track decay rate is the Pass-by Analysis software developed by TNO-Delft. This software makes it possible to gather these parameters by using pass-by measurements of a train using only 2 sensors: noise at 7.5m of track and rail vertical vibration. If the speed of the train can be logged and the composition of the train is known this method can lead to very good results compared with direct methods.

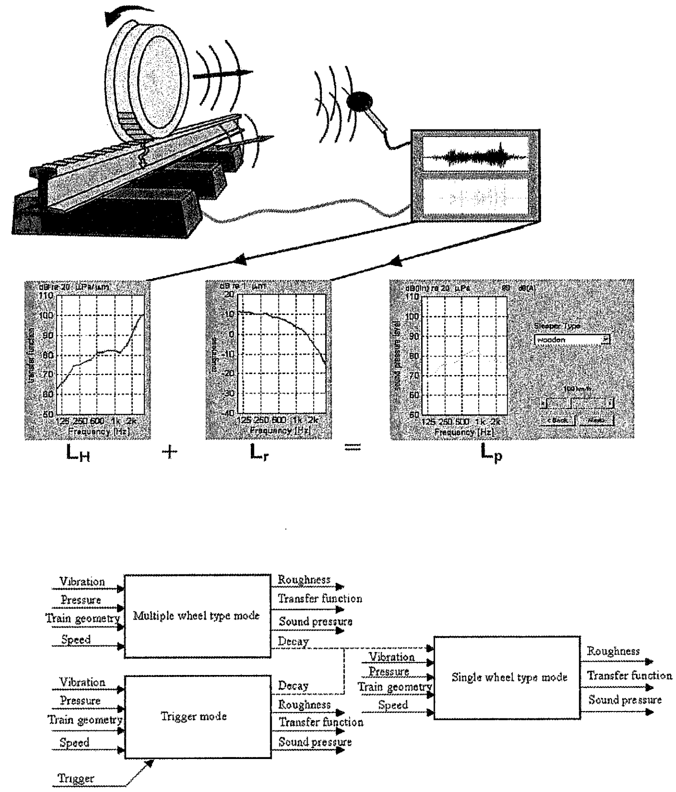


Figure 2.10 TNO-PBA software analysis possibilities

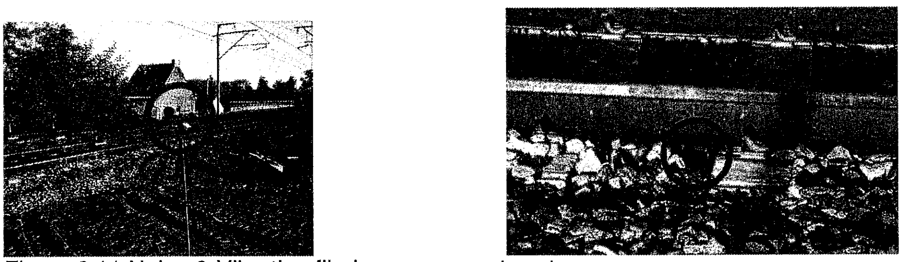


Figure 2.11 Noise & Vibration flied measurements setup

The software was used to process some pass-by from trains containing wheels with different quality of wheel roughness. On the measurement site the rail roughness was measured in a direct way and compared with measurements and processing's of the PBA-TNO method. Since the PBA-TNO software estimates always the combined wheel-rail roughness, we are able to determine the roughness as long as one of the two is significant lower than the other (-10 dB). This was tested by using a part of the train wheels in the analysis where the wheel roughness is low (M6 wagons: disk brakes) and exclude the locomotive (cast-iron brakes) outside the analysis. Figure 2.12-left shows the combined roughness of the complete train, while Figure 2.12-right shows the combined roughness without locomotive.

The roughness spectrum acquired this way corresponds very well with the direct measured roughness (Figure 2.13 curve D1) were a peak around 2.5 cm was found, corresponding with a grinding pattern. The indirect measurement shows lower amplitudes at 2.5 cm probably by the larger contact surface between rail and wheel compared to the rail -measurement device contact.

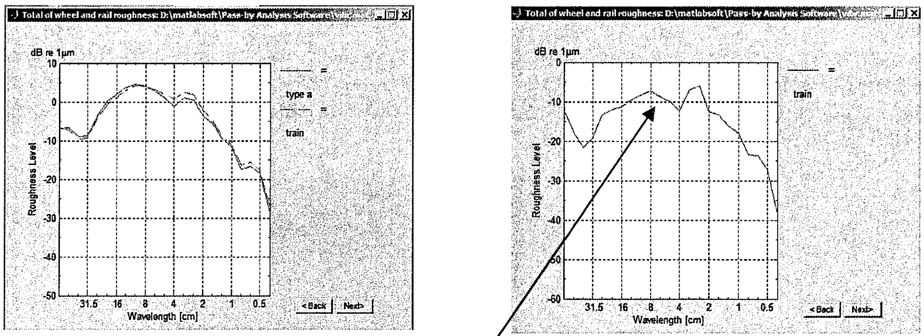


Figure 2.12 Calculated Combined wheel-rail roughness out off passby measurement.

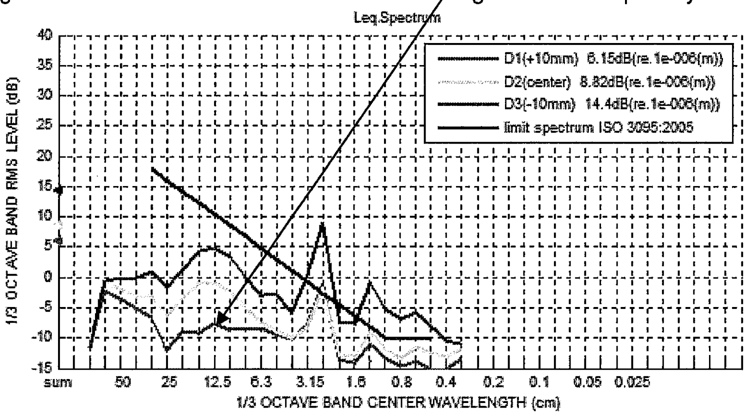
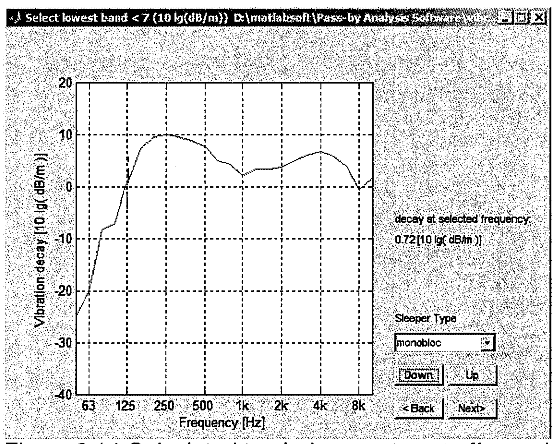


Figure 2.13 Direct measured rail roughness measurement.

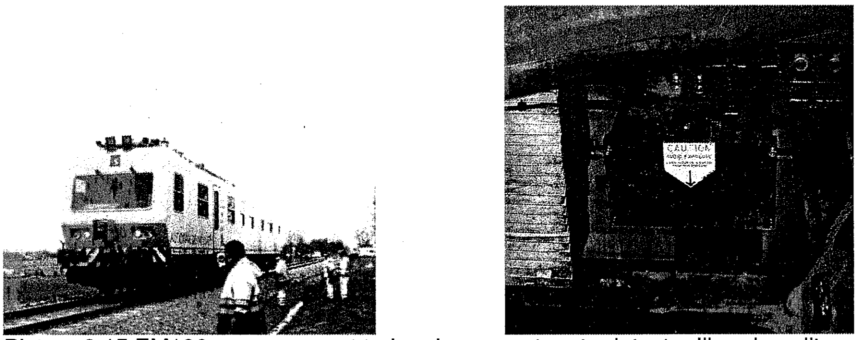


Also the track decay was calculated out of the pass-by measurement and shows good agreement with measurements. Figure 2.14 shows some processing results.

Figure 2.14 Calculated track decay rate out off pass-by measurement.

2.3.2.2 ANALYSIS OF EXISTING EM130 MEASUREMENT -TRAIN DATA

Infrabel has a measurement train, named EM130 that is equipped with various sensors meanly tot measure the track geometry as well as details about rails, overhead lines etc. This train is able to acquire all track parameters at a speed of 120 km/h. The complete Infrabel Network is measured two times a year.
Also laser systems are installed to gather data about the quality of the rail surface. The mean goal here is to locate positions where rail corrugation is present. These indirect measurements by means of lasers are further compared with direct measurements in order to see how they can be used or not in defining the "acoustic" quality of the track.



Picture 2.15 EM130 measurement train + Laser system to detect railhead quality

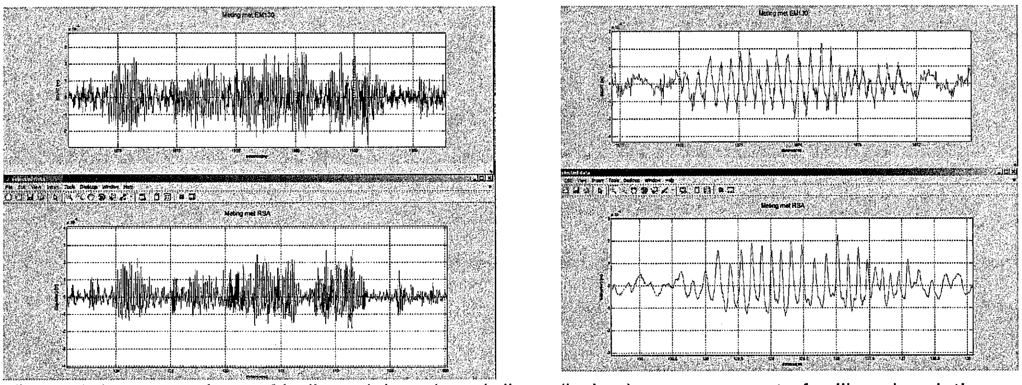


Figure 2.16 comparison of indirect (above) and direct (below) measurement of railhead variation

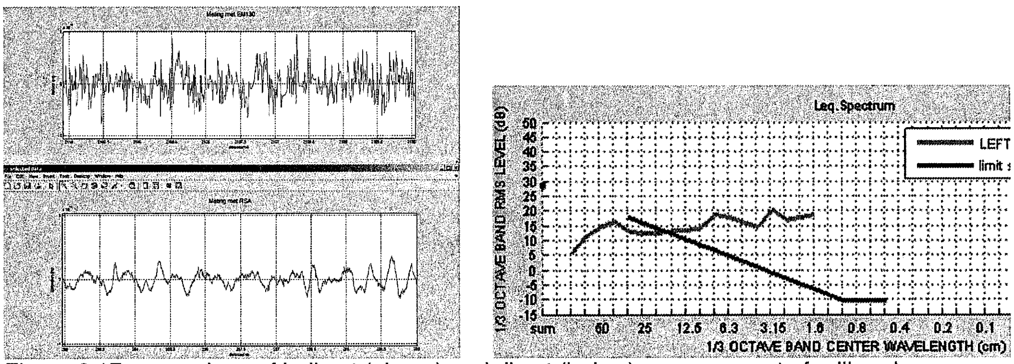


Figure 2.17 comparison of indirect (above) and direct (below) measurement of railhead

As figure 2.17 (right) shows a significant noise floor is present on the indirect laser measurement. A comparison of this noise floor with the ISO3095 or TSI reference curves made us conclude that we are not able to use these measurements to study an "acoustic quality" of the rail head.

2.3.2.3 MEASURING WHEEL ROUGHNESS OF ROLLING STOCK

As figure 2.18 indicates, Infrabel planned to install in 15 locations on his network weighting installations to weight axle loading and gather data about wheel quality. These installations will be equipped also by rail acceleration measurements and noise emission measurement. This data can afterwards be processed in other to determine the "acoustic" wheel quality. On these locations the rail quality has to be checked and if necessary be upgraded to a level below the TSI limits.

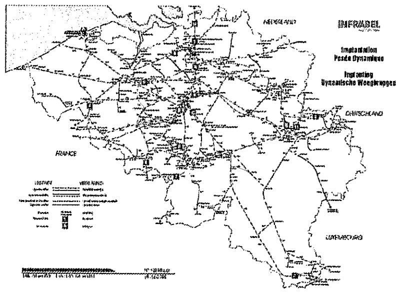


Figure 2.18 Planned locations were fixed noise & vibration measurement posts will be installed.

3 DEVELOPMENT OF AN INDIRECT MEASUREMENT SYSTEM TO MONITOR THE "ACOUSTIC TRACK QUALITY"

3.1 Basic idea

As showed in Figure 3.1 at the bottom right side, direct measurement systems are capable to measure the complete rail roughness spectrum down to amplitudes of 0.1 µm for the complete range of wavelength's. These punctual measurements show only a small fraction of the complete network.

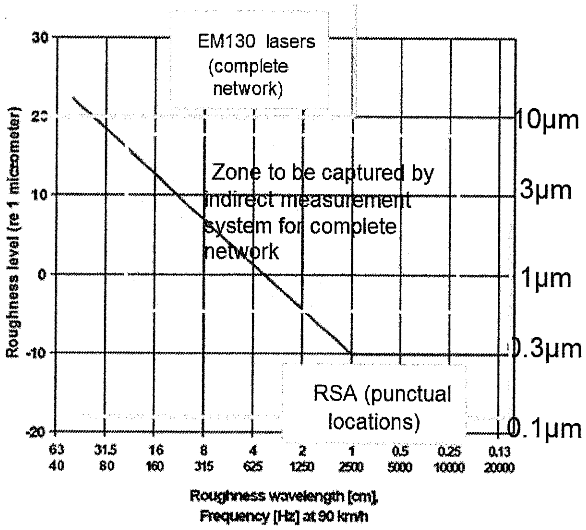


Figure 3.1 Direct and indirect measurement systems of railhead roughness

The laser system on the EM130 train is limited to amplitudes of 10µm and wavelengths starting from 1 cm (upper left side in Figure 3.1). So there is a need to fill the gap between these direct and indirect system, in other words, a secondary indirect system was developed.

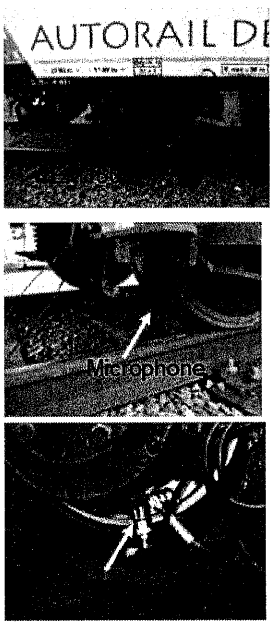
By mounting microphones close to the wheel rail contact parameters directly related to the wheel-rail roughness can be captured.

Because we capture the combined wheel-rail roughness we have to be sure that the wheel roughness spectrum of the EM130 wheels were the microphones are mounted is acceptable low. Installation of JURID in stead of CAST IRON break blocks enables us to maintain the wheel roughness below 1µm RMS. This will be checked monthly by indirect measurement on a track with good rail roughness, and every 6 months by a direct measurement on the running band of the wheel. Combining direct rail roughness measurements on several reference locations where different rail quality is present (from values below ISO3095 limit to values above 30 dB(re.1µm) will give us the possibility to fill up a calibration matrix. Speed correction can be done using the same approach as applied in SRMII. Finally, if we are able to log position of the EM130 with sufficient precision we can present the measurement results in a GIS environment.

At the same time, axle box accelerations are captured on both side in order to gather more information about rail quality, track defects, rail joints, etc.

3.2 Practical implementation on EM130

3.2.1 Prototype installation



- Permanent Installation of N&V sensors on the EM130 measurement train.
- Logging of the entire Infrabel network 2 times a year
- Accelerometers (4) on the axle boxes
- Microphones (2) to capture Wheel-Rail Noise emission
- Logging of position with DGPS (10Hz)
- Periodic verification of measurement wheel roughness (~ISO3095)

Picture 3.2 Indirect Prototype sensor installation

3.2.2 Processing of data

The prototype measurements are acquired and processed in the following way:

- 24 bit A/D conversion of 8 sensors at 20kHz sample frequency and real time streaming on Hard disk
- Real time Sampling of the DGPS train- positions at 10 Hz (at 120km/h about one position each 3meter, precision <0.5m)
- Continuous Time synchronization of data streams at 0.1 second precision
- Post processing:
    - Parallel 1/3 octave band filtering to spectra in a 0.5 Hz- 8 kHz frequency range, one spectrum per 0.1 second is calculated
    - Matching DGPS time - spectral time
    - Selection of frequency band to be visualized: via and band summing selection the user can select the band witch will be summed to be visualized.
    - Generation of *.kml file which can be imported by "Google earth"

3.2.3 Automation of data acquisition

The system is developed in a way that no user interface is required to gather measurement data. As control parameters the speed of the train and the position is used. Based on the speed window the system will be booted up, while GPS information will select were measurement data has to be acquired. When the measurement train reaches his parking place at the end of the day, which will be recognized by gps logging, a data wireless data transmission link will send only the post processed data (spectra and gps-coordinates) to the Infrabel servers.

3.2.4 Measurements result acquired by the prototype system

Figure 3.3 shows some results of a first post processing. By a user interface a band range can be selected, e.g. 100Hz-5 kHz. The energy in this frequency is summed and displayed as collared dots in the Google-earth window. This gives us in one view information about the acoustic quality of our track: corrugation into curves, higher noise emission on steel bridges and switches. Figure 3.4 shows axle box accelerations as a tool to display position and amplitude for corrugation. Only vibration energy in the band between 250-400 Hz was used to make the visualisation.

Figure 3.3 Measurement data presented in GIS environment

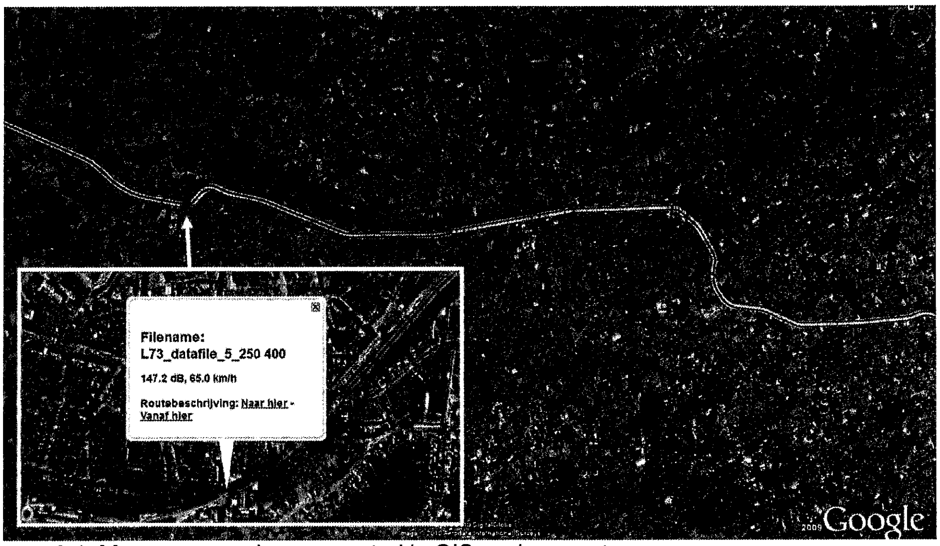


Figure 3.4 Measurement data presented in GIS environment

4 CONCLUSIONS

In this paper we tried to give some applications of how we can acquire direct and indirect track related parameters necessary to understand and predict better noise and vibration emission due to rail traffic.
A prototype system was developed that will be the base of gathering these parameters on a complete railway network.

The system should be operational in the coming months and can be used for:

- Determination of contribution of all track components to the noise emission
- Tool to verify if complaints about excessive noise emission can be traced back to infrastructure components
- Planning of urgent maintenance actions

In the spirit of 2002/49/EG directive it could be a tool to see where noise emission is Infrastructure based and also it can lead to more direct actions in the field in order to fight excessive noise and vibration emission.

5 REFERENCES

1. ISO 3095 Second edition 2005-08-15
2. EN 15461:2006-03
3. M.G.Dittrich, Track decay rate measurements using the PBA technique, Euronoise 2006