*XVII IMEKO World Congress*
*Metrology in the 3rd Millennium*
*June 22–27, 2003, Dubrovnik, Croatia*

# WAVELET SIGNAL PROCESSING APPLIED TO RAILWAY WHEELFLAT DETECTION

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**Abstract** - Aim of this research is the development of a reliable automated procedure for the detection of wheelflat faults in railway diagnostics. This kind of fault occurs when the train wheel slides on the rail. The wheelflat produced by sliding is a relevant cause of acoustic pollution, passenger discomfort, damage to rails and boogies. A good wheelflat detection diagnostics is common interest, both, for railway and vehicles operators.

The diagnostic method presented in this paper is based on the wavelet analysis of accelerometric signals obtained by an experimental campaign on a test train. The application field for wavelet analysis is new, and the results hitherto obtained show a better and simpler issues than classical time-frequency based analysis.

From a statistical standpoint, the experimental data are exhaustive base to achieve relevant diagnostic estimates in the train speed range between 10 and 100 km/h. The wavelet analysis processing method allowed to distinguish a wheelflat defected wheel up to 94% of the considered cases. Moreover, the same accelerometer signal giving wheelflat diagnostic is used to measure the train speed by a proper processing method leading results within a 2% by respect to commonly used commercial sensor.

Keywords: Technical diagnostics; wavelets signatures; vehicle comfort and safety.

## 1. INTRODUCTION

The wheelflat problem is a fault related to the wheel-rail contact force and, while the relationship between contact force and faults is a deeply investigated, the problem is far from completely solved [2-5]. Faulted wheels damage rails, and damaged rails cause a bad wheel-rail contact that could yield back to faults as wheelflat. For this reason, both from an economical and safety point of view, on-duty diagnostic would be an important achievement.

The measurements are accelerometric signals provided by a fixed experimental set-up arranged to test, at different speeds, trains with defected and not defected wheels.

The present investigation aims at two checks: detection of wheelflat faults; speed measurement by means of the same signals. The processing method, looking after both goals, is based on proper discrete-wavelet transform. The diagnostic and measurement procedures grant reliable pulse restitution and efficient computation time.

## 2. THE WHEELFLAT PHENOMENA

A railway wheel flat starts as a *facet spot* on the wheel rolling surface, caused by unintentional sliding on the rail. The reason for sliding might be defective antiskid device, or poorly adjusted, cast or defective brakes, or too high braking forces in relation to wheel/rail adhesion. Contaminations on the rail, such as leaves, grease, frost and snow, worsen the duty conditions.

As a flat establishes on the wheel tread, the temperature rise, caused by skidding, together with the rapid cooling into the adjacent material when the wheel starts rolling again, may lead to formation of martensite beneath the flat (*build-up phenomena*). If the defected wheel is not repaired or is not adequately machined off, the facet could degenerate into *long wheelflat* or face *build-up* of material along the wheel, and the eventually present cracks or new ones may develop due to rolling contact stresses.

The wheelflat fault produces local acceleration and high loads that damage both railway fixed facilities, such as rails, sleepers and ballast, and railway rolling materials, such as bearing and axle-boxes. Due to their impulsive nature, the flat impacts generate high frequency noise and vibration particularly annoying for passengers and outside people.

A sketch of wheelflat damaged wheel is shown in Fig. 1, where the length ***L*** of flatten zone is called *wheelflat length* (typical values of 25÷75 mm) and the length ***D*** is called *wheelflat depth*: these two quantity are linked by:

$$\begin{cases} L = 2 \cdot r \cdot \sin\beta \\ D = r \cdot (1 - \cos\beta) \end{cases} \qquad (1)$$

where: $r$ is the wheel radius and $\beta$ is the angle corresponding to the flat zone on the wheel circumference. The rail-wheel impulsive force, due to wheelflat defect, will be a function of train speed and wheelflat depth; the relationship between these quantities and the force is non linear, depending on the multi-masses dynamics of the moving train.

For the typical Italian railway case [1], the contact force, produced by wheelflat, increases with the train speed up to about 40 km/h, called critical speed, then slowly decreases up to 100 km/h thereafter it could be considered steady.

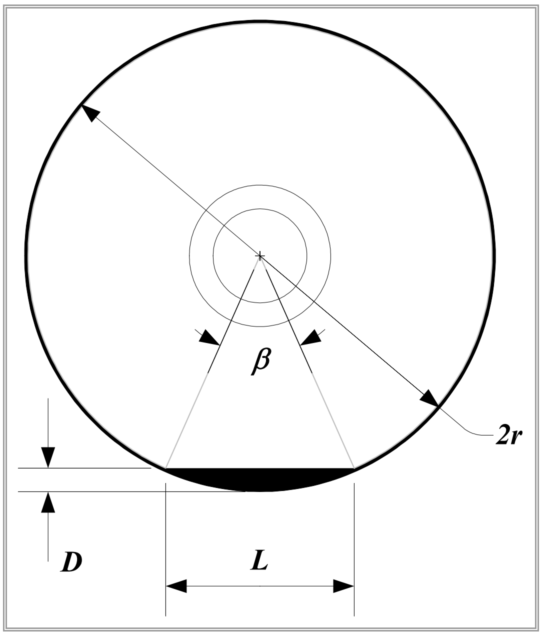


Fig. 1. Sketch of wheelflat

## 3. THE EXPERIMENTAL SET-UP

The study has been based on experimental assessments. The measurement campaign led to acquire rail acceleration for different wheelflat lengths and train speeds. The test set-up, includes a rail and a sleeper, each one instrumented with four accelerometers as shown in Fig. 2A, and a commercial axle-counter block to have reference speed measurements.

The experimental campaign aim at measuring the rail acceleration while the test train passed through the place. The test train transit were made at increasing speed from 10 km/h up to 100 km/h, with step of 10 km/h; for each speed five transits in different directions were measured. The test train was composed by:

- one locomotive E646, with six axles without defects;
- three testing coaches MDVC (four axles each one), five axles of these coaches are defected, with three different wheelflat lengths, as shown in Fig. 2B;
- one driving coach npBD, with four axles without defects.

For every train transit, the signals from the axle-counter block and from the four A1-A4 accelerometers or the T1-T4 accelerometers were acquired.

It is worth noting that, with an accelerometer signal, it is possible to detect the boogie, with damaged wheel, not the defected wheel itself. Actually, the boogie axle distance is 2.4 m, the wheel diameter is about 900 mm, so its envelope is about 2.8 m; hence, the envelope of the first axle wheel is superimposed on the one of second axle for a zone of about 200 mm. From a diagnostic point of view, this is acceptable, because the entire coach is sent to maintenance when one of its wheel is damaged.

On the contrary, to achieve proper measurement of the train speed, the detection, as accurate as possible in time domain, of the axle transit is really important.

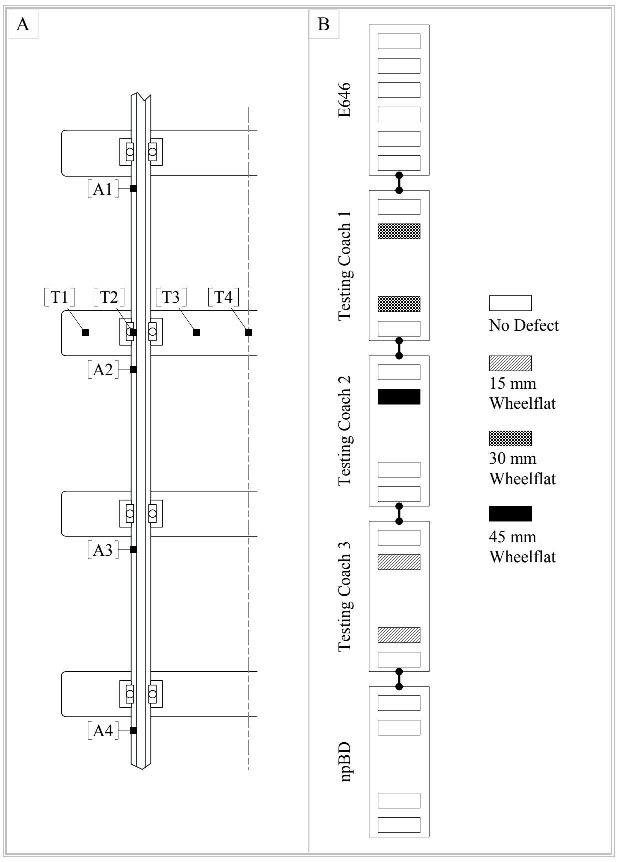


Fig. 2. *A:* Instrumented rail with position of accelerometer on rail (A1, A2, A3, A4) and on sleeper (T1, T2, T3, T4); *B:* Test train composition and map of defected axles with wheelflat length entity

The testing train composition permits to have for each pass-by:

- detection of 22 axles, to carry the speed measurement procedure[1];
- monitoring of 11 boogies, with 5 defective wheels, test the wheelflat diagnostic procedure.

The total experimental campaign brought to recordering 49 passes-by of the testing train, at ten different speeds (10-100 km/h) and both directions. This huge amount of data assures good statistical backing for the processing tools validation.

## 4. THE DATA PROCESSING

### *4.1. The wavelet choice*

An example of accelerometric signal is shown in Fig. 3. Without an adequate processing tool, it is hard to single out from such type of signal the axle transit on sensor, and even more difficult to distinguish the defected ones.

Both processing tools were based on wavelet transform. This choice was made taking in account the following prerequisites:

a) detection and time-localisation of pulses contained in broad band and high noisy signals;

[1] For each train transit only eight axles (the coach external ones) are useful in speed measurement procedure.

b) computation time efficiency for future application to on-line diagnostic;
c) shape asymmetries preservation in the accelerometric signature, due to wheelflat impacts.

Qualitative hints, obtained by previous studies [6][7], and the afore mentioned prerequisites drive our analyser toward purposely shaped discrete wavelet transform (*DWT*): the validity of this choice was confirmed also by preliminary tests.

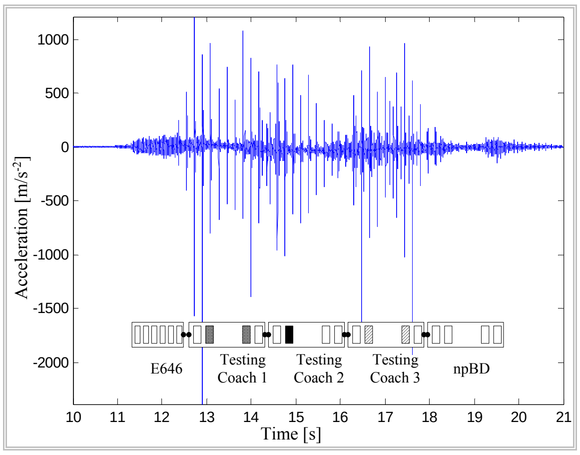


Fig. 3. Accelerometric signal for a train transit with nominal speed of 50 km/h; on the bottom of the figure is represented the train composition synchronized with the acquired signal.

*4.2. The processing tools ideas*

The wavelet transform, in a multi-resolution paradigm, is an algorithm that splits the original time-domain signal, into subsets of waveforms with different spectral contents, acting as a proportional passband set of filters. This property is powerful when it is necessary to split several contributes to get specialised information, like in our case study.

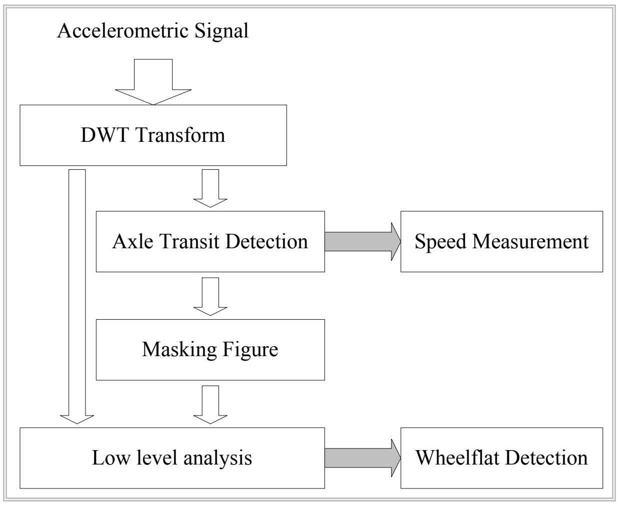


Fig. 4. Processing tools flowchart

The studied processing tools flowchart is exposed in Fig. 4. First of all, high level wavelet decomposition is used for the axle transit detection, these information are used to measure the train speed and, both, to create a masking figure, useful for the wheelflat detection. Then, the low level wavelet spectra are used to detect the wheelflat: in order to minimize false wheelflat-detection alarms, the masking figure is exploited for detection checks, whenever wheelflat pulses happen.

*4.3. Axle transit detection and speed measurement tools*

The information on axle transit are included in the last three levels coefficients, these are, thus, used to create a signal that contains only rail acceleration due to axle transit; the other details, noise and wheelflat effects, are mostly filtered by the reconstruction. The axle transit time is, then, obtained via a peak detection routine, Fig. 5, as preliminary output accelerometric signal of the processing tool.

The train speed is, accordingly, measured, from the time separation between the coach external axles: the result is compared with the train speed, given by the counter-axle block signal.

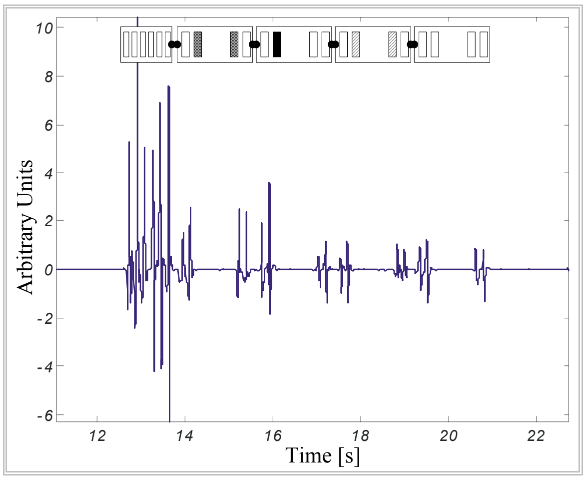


Fig. 5. Wavelet based reconstruction of rail acceleration due to axle transit, on the top is shown a sketch of test train

This processing tools carried out speed data that agree within 2%, with the standard measurement provided by the axle-counter blocks.

*4.4. Wheelflat detection tool*

From the processing method described above, the axle transit time-instants are obtained and these are utilized to create a masking figure: from the train speed, the period, ***T***, needed to a wheel to complete an entire loop on itself, is computed. The wheelflat defect could be placed in any point of wheel; so in the worst case it is located the opposite phase by respect to the contact point of rail accelerometer location. In this case, the wheelflat impact will occour at a distance of C/2 away from accelerometer, where C is the circumference of the wheel. Then, in the time-domain, the signal will be at maximum T/2 second after the reference timing.

The half-period, T/2, is the maximum time-distance from the axle transit instant, where the information of wheelflat impact could appear. The masking figure is created using axle transit instant and the T computed as told before; in order to lower the computation error instead of the period T, a slightly longer (10%) interval is used.

The low level wavelet coefficients are compared to a threshold, when the masking figure is "open", leading to a two states measurement: 1, if there is a defected boogies; and: 0 if there is a boogie with safe wheels. An example low level analysis, with applied masking figure, is shown in Fig. 6.

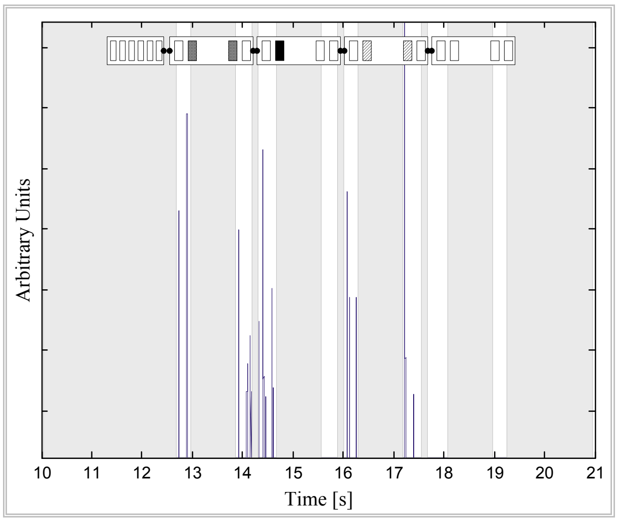


Fig. 6. Wheelflat detection with low level coefficient analysis and masking figure (the grey zone), in the upper side of figure is reported the synchronous testing train defect map.

The wheelflat assessment found out the 94% of defected axle detection, and the 100% safe axle detection. Moreover, thanks to the masking figure, almost all the false alarms are eliminated.

The issues of the multi-resolution wavelet transform are particularly effective, combining high and low level spectra to enhance the diagnostics safety, simultaneously giving a reliable measurement of the train speed.

## 5. CONCLUDING COMMENTS

The processing tools carried out from our research are very effective, well suited for the railway applications, in general, and, purposely, for the wheelflat diagnostic.

The wavelet transform technique proves to grant high versatility and the balanced selection of the functional base provides rather clear restitution of the symptoms, suggesting, as well, options for quantitative assessments, by means of accepted standards. These concepts are, presently, investigated.

The proper performance of the two-states assessment permits to work on improved wheelflat measurements, with different levels of the defect severity, aiming at the early detection of the hindrances, through experimental set-ups, easily located as fixed railway infrastructure.

The agreement of the wavelet-based speed measurement with the traditional one, let us to foresee the opportunity of avoiding the axle-counter block sensor from the measuring chain in the future experimental campaigns. The combined issues of multi-resolution analyses, properly exploited by the considered wavelet procedure, prove to be worthy tool to distinguish hierarchy of information, each time extracting the proper (generalised) spectral property.

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