Iran University of Science and Technology

International Journal of

Railway Research

ISSN: 2423-3838

Wheelset Condition Monitoring Based on Pass-by Vibration Signals

Hamid Masoumi[1*], Frederik Vermeulen[2], Tom Vanhonacker[2]

[1]D2S International (BE)

[2]APT (BE)

ARTICLE INFO

Article history:

Received: 21.06.2018

Accepted: 12.08.2018

Published: 15.12.2018

Keywords:

Vibration-based

Wheelflat

Wheelset monitoring

Wheelset maintenance

A B S T R A C T

Apart from regular wheel wear such as decreasing wheel diameters and reduced flange thicknesses and heights, wheelflats (WF) and oval wheels (or OOR, Out-Of-Roundness) are the most common wheelset problems for railway vehicles. Within the FP7 Research Project "Saferail", APT has developed an innovative wheelset monitoring system so-called "Wheelflat and Out of Roundness Monitoring (WORM) system". The monitoring system is installed on the track and is based on the vibration signals measured during the passage of trains. The main advantages of vibration signals are the short measurement time of just a few seconds, and the very limited number of sensors to be installed. As a consequence, the track space required for the installation of the equipment is very limited and thus the associated installation cost is significantly reduced. Early detection of wheelflats combined with appropriate corrective action not only contributes to lower track stresses and wear, but also results in a longer wheel life. The WORM system reports all measured vehicles via a web interface so no user software installations are necessary. A historical overview of measurements and alarms can easily be retrieved from the proposed system. Immediate alerts can be programmed to be sent by email or text message. These advantages make the APT-WORM system as a strong device to increase the service life of the wheel and decrease the maintenance cost by optimizing the maintenance intervals.

1. Introduction

Inefficient wheelset maintenance negatively influences passenger comfort and causes annoyances to nearby residents due to increased noise and vibration levels. Wheelset defects can possibly cause accidents and may result in a significant damage to the rail network. The wheelset does not keep the same configuration and geometry during its life cycle and, due to operational aspects and vehicle/track interaction, defects on the wheelset can arise.

Apart from regular wheel wear such as decreasing wheel diameters and reduced flange thicknesses and heights, wheel sliding causes severe wear and formation in the wheel/rail contact surface such that a part of the wheel tread is flattened and burnt so-called "wheelflat", see "Figure 1". Wheelflats (WF) and ovalization (or OOR, Out-Of-Roundness) are the most common wheelset problems for railway vehicles. The wheelflat may happen because of the lack of adhesion at the wheel/rail surface (e.g. due to leaves on the rail head) or defective or frozen brakes. Such a flat formation can have a length from 50 to 100 mm, [1].

When the wheel rotates, these defects generate a large impact force on the track that may damage the rails and the sleepers and causes high level of noise and vibration. Recently, several research programs deal with the induced noise and vibration near the rail network due to the wheel/rail surface

*Corresponding author
Email address: hamid.masoumi@d2sint.com

[DOI: 10.22068/IJRARE.5.2.1]

irregularities and defects using a dynamic wheel/track interaction model [1, 2].

Figure 1. Wheelflats

"Figure 2" shows the mechanism of the wheel/rail contact in presence of a flat on a rolling wheel surface. Wu and Thompson [2] shown that the amplitude of the generated dynamic force depends on the form and the two dimension of flats. Such that the rounded flat generates less impact force than a new sharp edge flat (with the same dimension). Depending on the flat condition, the maximum contact force could reach 3 to 5 times of the static axle load, [1].

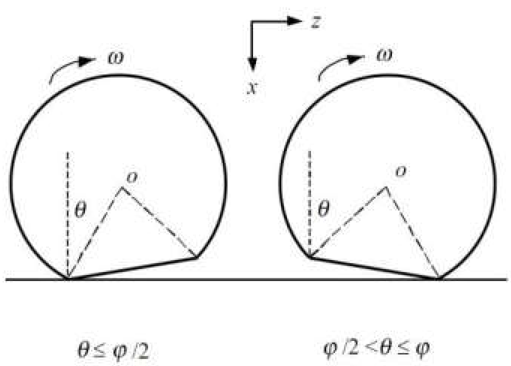

Figure 2. Rolling of a wheel with an idealized flat, after Wu & Thompson (2001) [2]

Normally, small flats may be eliminated by abrasion of the brake blocks during brake applications. However for a moderate to big flat, the wheel requires returning. Another important defect is the axial run-out (ovalization), Figure 3. The ovalization as a part of the periodic defects, is a radius deviation with wavelength which corresponds to half of the circumference of wheel. The correction method is to turn the wheel.

Within the FP7 Research Project "Saferail", APT, in cooperation with the Flemish Public Transport Company De Lijn (Belgium) [3], have developed an innovative wheelset monitoring system so-called "Wheelflat and Out of Roundness Monitoring (WORM) system". The monitoring system is installed on the track and is based on the vibration signals measured during the passage of trains. Detailed signal analysis enables the detection of various anomalies related to the wheelset such as wheelflats, wheelout-of-roundness and other deviations (problems with the suspension, bearings …).

2. Measurement Setup and Instrumentation

The system is an accelerometer-based wheelflat detector. "Figure 4" illustrates a side view and cross section of the measurement setup including 4 accelerometers on the track and the central unit beside the track. The sensors are sensitive accelerometers, which are fixed on the rail tip, "Figure 5. The sensors are robust and easy to install and maintain. They withstand typical railway EMC conditions, as well as water and dust ingress, corrosion, protection for fallen overhead lines, and dragging debris from trains. The sensitivity of the sensors needs to be calibrated in function of the stiffness of the rail and track bed. For this purpose, the track impedance is investigated before the Worm system installation, "Figure 6". An in-situ dynamic test on the track will be performed to determine the track mobility as well as track decay rate. The track decay rate shows
the rate of vibration amplitude attenuation along the track length. The monitoring system itself will be placed inside a cabinet next to the track, while the accelerometers will be connected to the central unit using the protected cables. The central unit is housed in a street cabinet in a more protected environment. Operating temperature can be from -20°C to +50°C and ingress protection is to IP44, "Figure 7".

[DOI: 10.22068/IJRARE.5.2.1]

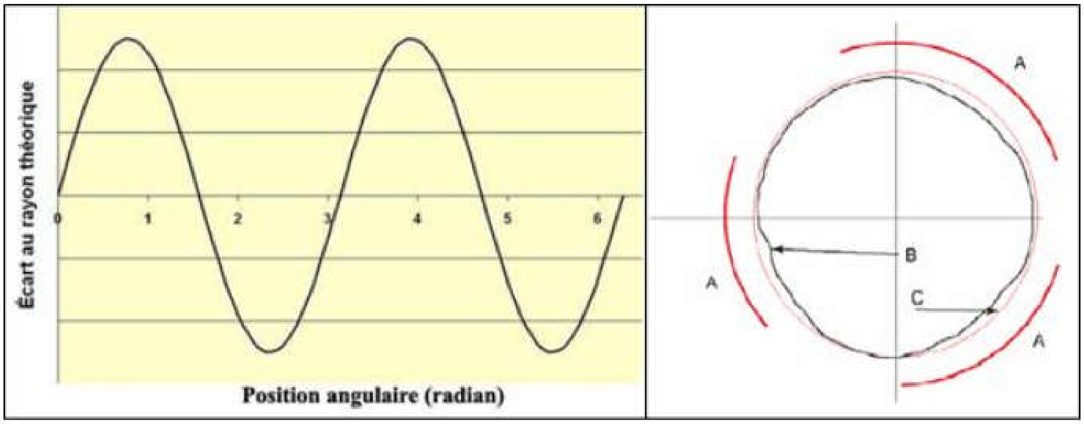

Figure 3. Axial run-out (ovalization)

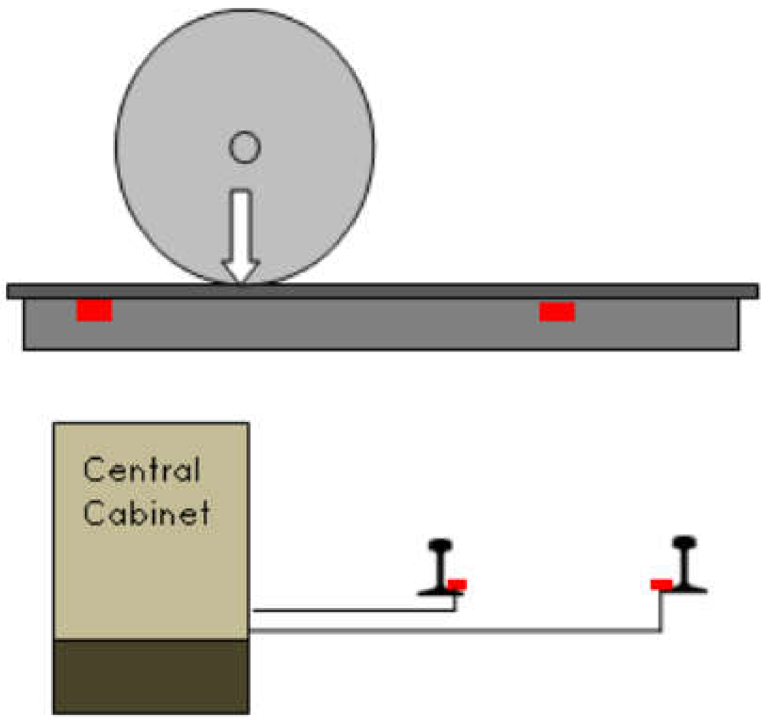

Figure 4. The measurement setup

3. Signal Processing and Flat Detection Algorithm

The analysis of the measured vibration is performed on-site in a real time. An embedded computer with a powerful processor guarantees that the results are available immediately after a vehicle passage.

The central unit comprises a processing unit with Digital Signal Processing (DSP) functionality, which enables the performance of spectral analysis, digital filtering and criteria evaluation. The procedure is schematically illustrated in a flowchart in Figure 8. The first step after acquisition of the acceleration signals measured on the rail is the detection and verification of an actual vehicle passage.

[DOI: 10.22068/IJRARE.5.2.1]

Figure 5. Protection of the sensors on the rail

Figure 6. Track decay rate test

For each sensor, the part of the signal is detected that corresponds to the vehicle passage. The result for each sensor is compared to the other sensors and it is decided whether an actual vehicle passage occurred. Other events that might have occurred are e.g. other vehicles like busses that pass the sensors (in case of an embedded system with mixed traffic) or short disturbances in one or multiple sensors. After confirmation of an actual vehicle passage, the signals are conditioned before further processing. This conditioning step includes low-pass filtering, detection of signal offsets and other filters. Besides an output of the analysis, the vehicle speed is a parameter that is used in both the axle detection algorithm and the wheelflat detection algorithm. The speed is determined by evaluating the time difference between the signals measured on the same rail.

[DOI: 10.22068/IJRARE.5.2.1]

Figure 7. The central cabinet of the monitoring system

Since the distance between both sensors is known, an accurate determination of the vehicle speed is possible. The detection of the positions of the axles in the signal is based on the knowledge that the vibration levels are highest when the axles pass the sensor location. Therefore, the acceleration signal is filtered using velocity dependent filters, such that an envelope function is retained. The maxima in this function correspond to the locations of the axles. An example of the axle detection process is shown in Figure 9. The top figure shows the original signal in blue and the envelope in black, after the application of the appropriate filters. The final step is the determination of the maxima in the envelope function to find the axle positions. In order to avoid maxima that do not correspond to axles, several rules are implemented to eliminate these spurious maxima.

The detection of wheelflats is based on the typical pattern generated by a wheelflat; a series of consecutive spikes caused by the impacts of the wheelflat on the rail.

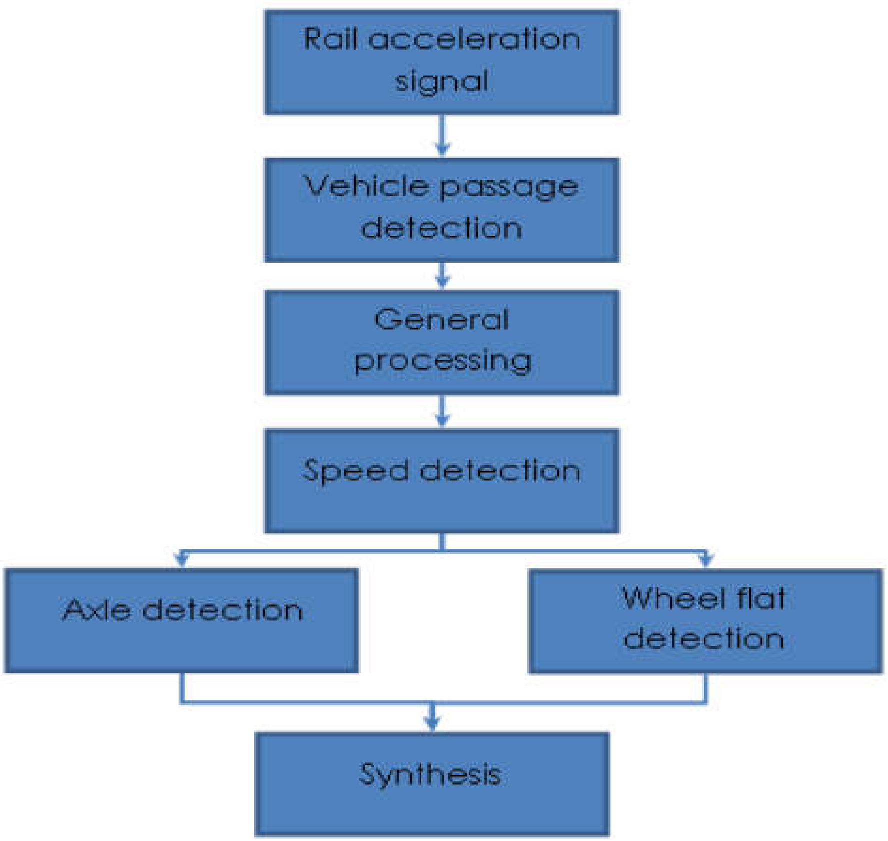

Figure 8. The analysis procedure

[DOI: 10.22068/IJRARE.5.2.1]

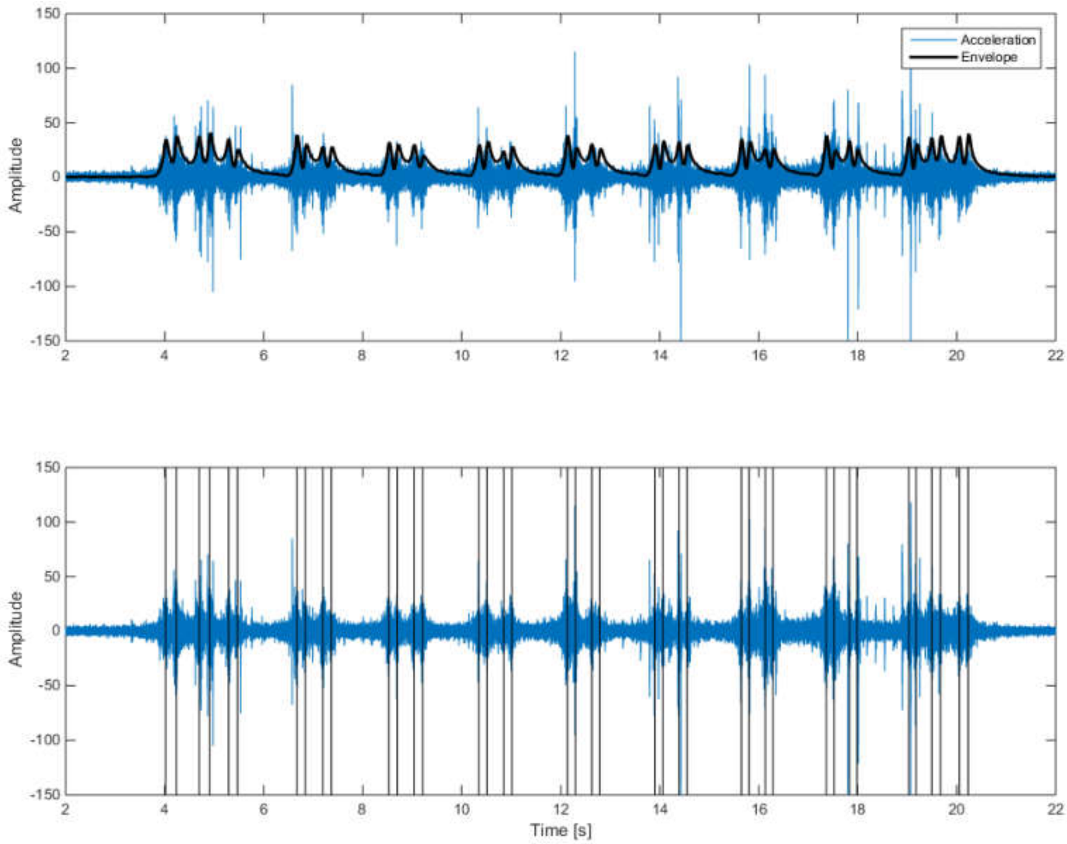

Figure 9. The measured acceleration signals

The spacing of these impacts (expressed in seconds) is determined by the wheel diameter and the vehicle speed. An algorithm has been developed to detect this pattern in the signal. The signal is first conditioned using speed dependent filters in order to remove the "normal" vibration, i.e. the vibration caused by the passage of the vehicle, without wheelfaults. The result is a signal in which the impact peaks are emphasized. The second step is the detection of the typical pattern in the conditioned signal using correlation techniques. "Figure 10" illustrates the procedure clearly showing the typical pattern of consecutive impacts. The gray lines show the impacts that have been identified by the algorithm as being part of the wheelflat pattern.

4. Reporting and Interfaces

The proposed system has a standard reporting software, that reports the outputs both on a website interface and in an excel database, Figure 11. The report consist of full information per train passage: Time of passage, Speed of train, Number of axles, Flat wheels, and Maximum wheel impact. In addition, the system can be programmed for an immediate alert to be sent by an email or a text message. The alarm configuration can be programmed according to the thresholds defined by customer. "Figure 12" shows an overview of the alarm configuration and text messages. Daily or monthly reporting can also be configured. The modular approach of the system allows the replacement of generic modules such as the vehicle identification, the presence detector, alerting, and data download towards a maintenance management system. These generic modules are typically specified by the customer.

[DOI: 10.22068/IJRARE.5.2.1]

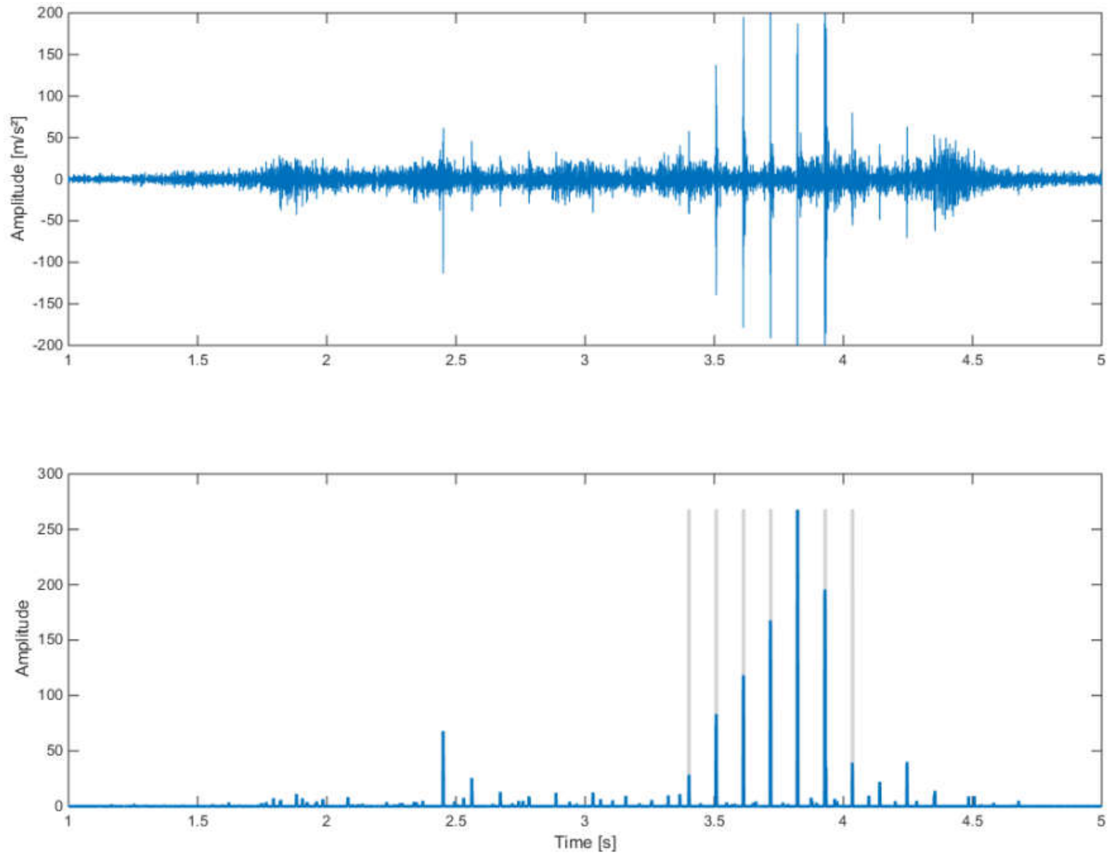

Figure 10. The measured signal and identified impacts

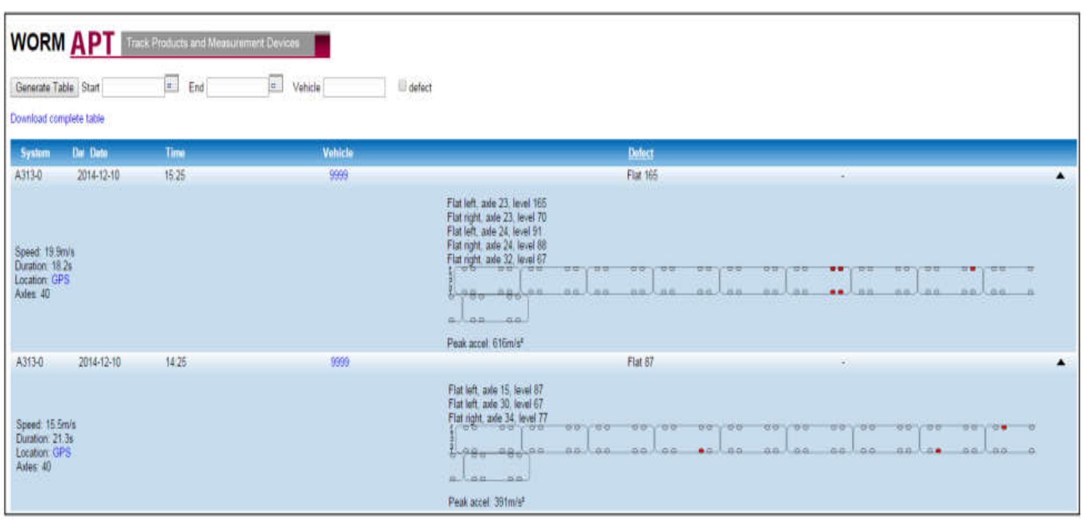

Figure 11. Results of the wheelflat monitoring on a website interface

[DOI: 10.22068/IJRARE.5.2.1]

Figure 12. Alarm configuration and text message example

5. Conclusions

The efficiency of the APT-WORM system has been very well approved in several sites in Belgium and abroad rail networks. The monitoring system is fully operational since 2009 and successfully helps to optimize the maintenance intervals for different railway network.

Early detection of wheelflats and out-of-roundness combined with an appropriate corrective action, not only contributes to lower track stresses and wear, but also provides a longer service life of the wheelset. These advantages make APT-WORM system to payback its cost within a very short period of time. Depending on the configuration of the wheelsets (use of wheel rims, solid wheels, etc.), the number of axles passing over the monitoring system, and the prevailing maintenance intervals, the payback period, as confirmed by De Lijn, ranges from 11 to 18 months. This estimation only considers the increased service life of the wheels and it does not take into account for the secondary gains such as increasing the passenger comfort, decreasing the track wear, and reducing the noise and vibration emission.

References

[1] H. Masoumi, P. Vanhonacker, and D. Dias, Maintenance limits - Wheel & rails surface, Deliverable 3.1, FP7 European project Cargovibes , July 2013.

[2] Wu T.X. and Thompson D.J., A hybrid model for wheel/track dynamic track interaction and noise generation due to wheelflats, ISVR Technical memorandum N. 859, January 2001.

[3] T. Vanhonacker, M. Laeremans, and E. De Donder, Low-cost online wheelset condition monitoring of light rail vehicles, Rail Engineering International, 2012, pages 6-8.

[DOI: 10.22068/IJRARE.5.2.1]