

## Low-cost on-line wheelset condition monitoring of light rail vehicles

Within the framework of the FP7 Research Project “Saferail”, co-funded by the European Commission, APT - Track Products and Measurement Devices, Belgium, in cooperation with the Flemish Public Transport Company De Lijn (Belgium), developed an innovative low-cost wayside wheelset monitoring system specifically for light rail vehicles (LRVs). De Lijn has installed two such wayside monitoring systems on its network: one at the exit of its LRV workshop in Antwerp and another one on a line along the Belgian coast. This article looks at the systems installed by De Lijn, as well as at a number of other installations.

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### THE APT-WORM (WHEEL FLAT AND OUT-OF-ROUNDNESS MONITORING) SYSTEM

Apart from regular wheel wear, such as decreasing wheel diameters and reduced flange thickness and height, wheel flats and oval wheels (or out-of-roundness) are the most common LRV wheelset problems. The APT-WORM (wheel flat and out-of-roundness monitoring) system, which is based on the measurement and detailed signal analysis of the vibrations generated by passing wheels, enables the detection of these types of wheel wear. Vibration spectra are commonly used for non-destructive testing, since these contain comprehensive information about the object under test. The vibration spectra of railway vehicles are not only altered by wheel flats or wheel out-of-roundness, but also by other defects, such as broken wheel gummies, wheel shelling, wheel cracks, and bearing defects.

#### Vibration measurement set-up

The main advantages of vibration analysis techniques are the short measurement time of just a few seconds, and the very limited number of sensors that need to be installed, only one per rail.



Fig. 1: APT-WORM equipment being installed in an embedded track



Fig. 2: APT-WORM sensors installed on ballasted track

As a consequence, the track space required for the installation of the APT-WORM equipment is very limited, and the associated installation costs are minimal (Figs. 1 and 2).

It is important to select the right location to install the two measuring sensors (one per rail).

The location of installing the measuring sensors at the LRV workshop of the Lijn in Antwerp was determined based on the following considerations:

- a high number of passing LRVs;
- a minimum of disturbance from switches or curves;
- a minimum of interference from electrical equipment;
- a travel speed of the LRVs of more than 10 km/h;
- an availability of data and power connections.

At the LRV workshop of De Lijn in Antwerp, the measuring sensors are located in a section of embedded track that is subject to heavy traffic, with buses also entering/leaving the depot and, thus, they are housed in a steel casing for protection. The steel casings are dimensioned in such a manner so as to avoid any interference with the LRV wheels, and to ensure that no mechanical connections or vibrations are introduced that might influence the vibration measurements. The small processing unit is installed in a building adjacent to the track (Fig. 3).



Fig. 3: The APT-WORM installed at the LRV workshop in Antwerp

### Vibration measurement result analysis

The analysis of the vibration measurement results is performed on-site in real time. An embedded computer with a powerful processor guarantees that the results are available immediately after a vehicle passage. The central part of the computer comprises a processing unit with Digital Signal Processing (DSP) functionality, which enables the performance of spectral analysis, digital filtering, and criteria evaluation.

Each type of wheel defect exhibits a different alteration of the measured vibration signal. As shown in Fig. 4, wheel flats with a length of less than 10 mm can easily be picked up in a time domain analysis after applying some basic processing algorithms. However, as also the vehicle speed itself alters the vibration signals, a speed-depending wheel-flat detection algorithm is added in the processing. For wheel out-of-roundness, however, a time domain analysis alone is not sufficient. By analysing the frequency domain, wheel out-of-roundness under all circumstances can be detected.

Apart from wheel defect detection as such, the vibration measurements allow a qualitative comparison of the dynamic loads on the track from one vehicle to another. Strongly deviating dynamic loads can be symptoms of unknown problems. Subsequent manual inspection of vehicles showing deviating dynamic loads have exposed, for example, on-board braking systems that were not properly aligned, and suspensions that were not correctly tuned.

### Interfaces and user interaction

The system foresees in logical outputs via relays (voltage-free contact) to allow activation of alerts or interfaces with train control systems. The APT-WORM system, of course, interfaces with existing vehicle identification systems via RS232, RS485 or current loop. Optionally, a camera can be installed that is activated by the passing vehicle and then produces a "snap shot" picture of the vehicle, including its identification number.

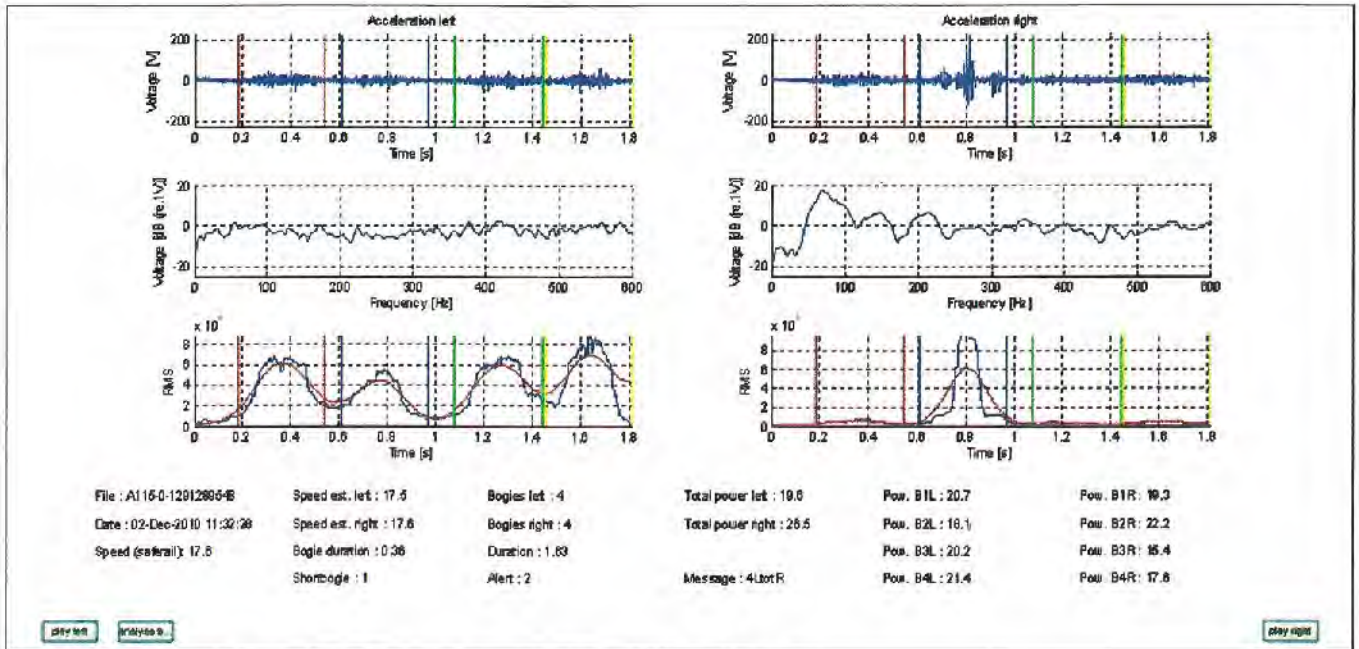


Fig. 4: Time & frequency domain plot indicating the passage of four normal wheels (left) and the passage of a vehicle with a wheel flat on the second axle (right)

Figure 5 shows a screenshot of the APT-WORM GUI. It features a table with columns for Start, End, Pos, VehID, Datafile, Jpg, Speed, Rst, Oval, WC, and Peak accel. The table contains five rows of data, each representing a vehicle passage with associated speed, position, and peak acceleration values.

Start	End	Pos	VehID	Datafile	Jpg	Speed	Rst	Oval	WC	Peak accel
2010-09-15 17:51:58	2010-09-15 17:52:06	51.1570953 2.748937E	6049 Kust	012		13.2	L-3			0.50
2010-09-15 17:37:31	2010-09-15 17:37:41	51.1570953 2.748937E	6034 Kust	012		14.0				0.72
2010-09-15 17:23:40	2010-09-15 17:23:50	51.1570953 2.748937E	6001 Kust	012		15.0				0.66
2010-09-15 17:17:57	2010-09-15 17:18:07	51.1570953 2.748937E	6023 Kust	012		15.2				0.62
2010-09-15 16:53:46	2010-09-15 16:53:56	51.1570953 2.748937E	6042 Kust	012		16.6	R-2			0.57

Fig. 5: Example of a graphical user interface (GUI) developed for the APT-WORM system

The APT-WORM system generally requires an Internet or LAN connection, either via a wired interface to the operator network, or via a wireless GPRS/UMTS connection. This connection is used for data storage at the APT HQ, and for remote system inspection and configuration.

In Fig. 5, an example of a graphical user interface (GUI), developed for the APT-WORM, is shown. Every vehicle that passes is added to the top of the list in real time. Also, the vehicle identification and a "snap shot" picture taken by the system camera are shown. The APT-WORM system reports all measured vehicles via a web interface, so that no user software installations are necessary. A historical overview of measurements and alerts can easily be retrieved from the system.

Immediate alerts can be programmed to be sent by email or text message (Fig. 6).

Daily or monthly reporting can be configured. The modular approach of the system allows the replacement of generic modules, such as that of vehicle identification, defect presence detection, alerting, and data download to a maintenance management system. Those generic modules are typically customer specific.



Fig. 6: Example of a text alert

The on-line APT-WORM system communicates with an off-line database; this allows trending that can be used to refine the alert levels, and provides a safe data storage.

### THE APT-WIM (WEIGH-IN-MOTION) SYSTEM

As noted earlier, the wayside monitoring system installed by De Lijn on a line along the Belgian coast includes a vehicle weigh-in-motion system: the APT-WIM. By means of strain gauges, the dynamic weight of passing LRVs is measured. The APT-WIM uses the same processing unit with Digital Signal Processing (DSP) functionality as the APT-WORM system. Since rail stress is directly related to the weight of a railway vehicle, a strain gauge measurement can be used to determine the weight of each axle. For each system, a calibration has to be performed using the known axle weight of certain vehicles. The APT-WIM system can be installed independently, or in combination with the APT-WORM system.

### SUCCESS OF THE APT-WORM

Apart from wheelset defect detection, the APT-WORM system quantifies the dynamic impact of the vehicle on the track, allowing trending over a longer period and a better organisation of the maintenance intervals. Since its installation at the exit of the main LRV workshop of De Lijn in Antwerp – in an embedded section of track – in 2009, the APT-WORM system has successfully helped to optimise the maintenance intervals of its fleet of more than 65 LRVs. The APT-WORM system on the line along the Belgian coast – featuring ballasted track – was installed in 2010 (Fig. 7), and includes a WIM (weigh-in-motion) module.

The service life of LRV wheels is mainly determined by the amount of metal that is removed during wheel truing, carried out at fixed km intervals. The APT-WORM system enables a changeover to condition-based wheel truing, which results in significant cost savings. By keeping LRVs without wheel defects running, the truing intervals can be increased significantly. Moreover, early detection of wheel flats and out-of-roundness results in a lower amount of metal removal during wheel truing and, thus, an increase in the service life of the wheel.

### OTHER APT-WORM INSTALLATIONS

In 2011, several other APT-WORM installations followed in Belgium; e.g. on LRT line extensions built within the framework of PPP contracts, where the monitoring systems turned out to be of particular interest to the track owners (the contractors and their banks) (Fig. 8). Another one was installed on Line 139 of the Infrabel network near Leuven, to specifically monitor the condition and impact on the track of freight train wheelsets. Further, in 2012, installations are scheduled on both the LRT and metro network of MIVB/STIB in Brussels.

Outside Belgium, APT-WORM systems have been installed in Manila, the Philippines, and the USA where, apart from optimising wheelset maintenance intervals, they are used to stop or slow down vehicles that have an unacceptable impact on the track.



Fig. 7: The APT-WORM installed on ballasted track



Fig. 8: The APT-WORM installed in a newly-built track

### OUTLOOK

Further additions to the wheelset monitoring system are being investigated. For instance, plug-in modules for wheel diameter measurement and flange thickness/height, without having to measure the complete wheel profile, are currently undergoing tests. The modular approach of the APT-WORM system allows customers to devise a wheelset inspection that is based on their individual needs and budgets.

### CONCLUSIONS

Early detection of wheel flats and out-of-roundness, combined with appropriate corrective action, not only contributes to lower track stresses and wear, but also to a longer service life of the wheel, making the APT-WORM installation pay for itself 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 pay-back period for the APT-WORM system, as used by De Lijn, ranges from 11 to 18 months. This calculation only considers the increased service life of the wheels. It does not consider the secondary gains, such as increased passenger comfort, decreased track wear, and reduced noise and vibration emissions.

**Dr.-Ing. habil. Rüdiger G. Wettschureck, Consulting Engineer in Technical Acoustics, who has many years of experience and expertise in this field, offers his assistance for:**

- the evaluation of noise and vibration emissions near planned/existing railway lines, and the selection of noise and vibration abatement measures required;
- the interpretation/construction of structure-borne noise reduction measures for both above and underground railway line projects (bridges of different design, open lines, tunnels);
- consultancy during the planning, tendering and execution process of structure-borne noise reduction measures with respect to planned and/or existing railway lines (e.g. resilient rail fastenings, resilient sleeper pads, ballast mats, floating slabs, mass-spring systems);
- the calculation of expected reduction of structure-borne noise levels after the installation of reduction measures, by means of proven and certified calculation methods and models (wheel/rail impedance models, Timoshenko beam and elastic half-space, etc. (see, for example, DIN V 45673-4, Edition July 2008)).

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