Low Cost Online Wheelset Condition Monitoring for Light Rail Operators

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Introduction
The rail industry is in a state of rapid transformation due to safety, environmental, societal, and economic demands. Wheelset defects can possibly cause accidents and account for a significant portion of the damage to the rail network. Inefficient wheelset maintenance negatively influences passenger comfort and causes annoyances to nearby residents due to increased noise and vibration levels. In the last five to ten years, significant advances have been made in wayside monitoring systems with a primary focus on conventional and high-speed rail vehicles. Wayside monitoring systems are less common in light rail operations and are often adapted from developments for conventional and high-speed rail vehicles. This comes with the generation of an overflow of measurement data that is generally barely used. Further, because of the lower number of vehicles operating on the light rail network, this results in a high cost per inspected vehicle.

Within the FP7 Research Project “Saferail“, co-funded by the European Commission, APT, in cooperation with the Flemish Public Transport Company De Lijn (Belgium), developed an innovative low cost monitoring system specifically for light rail operators. The wayside monitoring system is based on the measurement of the vibrations generated by the passing wheels. Detailed signal analysis enables the detection of various anomalies related to the wheelset such as wheel flats, wheel-out-of-roundness and other deviations (problems with the suspension, bearings ...). Early detection of wheel flats combined with appropriate corrective action not only contributes to lower track stresses and wear, but also to longer wheel life, making the installation pay for itself in a very short period. De Lijn has installed two such wayside monitoring systems in its network: one at the exit of a tram workshop in Antwerp, the other one on the line along the Belgian coast. The latter also includes a vehicle weigh-in-motion system. Several other installations are described in this article.

The APT-WORM (Wheel flat and Out of Roundness Monitoring) system
Apart from regular wheel wear such as decreasing wheel diameters and reduced flange thicknesses and heights, wheel flats (WF) and oval wheels (or OOR, Out-Of-Roundness) are the most common wheelset problems for urban light rail vehicles.

Vibration spectra are commonly used for non-destructive testing since they contain comprehensive information about the object under test. The vibration spectra of railway vehicles are not only altered by flats or wheel-out-of-roundness, but also other defects such as broken wheel gummies, wheel shelling, wheelcracks and bearing defects cause variations in the vibration spectra.
The main advantages of vibration analysis techniques are the short measurement time of just a few seconds, and the very limited number of sensors to be installed, only one on each rail. 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.

Figure 1(a) shows a wheel gummy as used on PCC tram vehicles, which can break off. Figure 1(b) illustrates the very limited space requirements of the APT-WORM installation in the street surface. Figure 2 shows an installation in ballasted track.

**Vibration measurement setup**

Two accelerometers, installed in a single location on each rail capture the vibrations. The selection of an appropriate location is important in order to have the most favourable measurement conditions. The location at the workshop of De Lijn in Antwerp was determined considering the following:

- Maximum possible number of trams passing over the measurement system when entering or leaving the workshop;
- Minimal disturbance from switches or curves;
- Minimal interference from electrical equipment;
- Vehicles with a speed of more than 10 km/h;
- Availability of data and power connections.

Finally, the installation was done in a section of embedded track that is also used by the busses leaving the depot and thus subject to heavy traffic. The sensors are therefore protected by a steel casing. The sensor casing must be dimensioned to avoid any interference with the tram wheels and ensure that no mechanical connections or vibrations are introduced that might influence the vibration measurements.
Vibration analysis results

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

Each type of defect exhibits a different alteration of the measured vibration signal. As shown in figure 3 below, 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, also the vehicle speed itself alters the vibration signals. Therefore, a speed depending wheel flat detection algorithm was added in the processing. For OOR, a time domain analysis alone was not sufficient. An analysis of the frequency domain offered the solution to detect the OOR under all circumstances.

![Figure 3. Time & frequency domain plot indicating a passage of 4 normal wheels (left) and a passage of a vehicle with a flat on the second axle (right)](image)

Apart from the defect detection as such, the measurements allow a qualitative comparison of the dynamic loads on the track from one vehicle to the other. Strongly deviating dynamic loads can be symptoms of unknown problems. The manual inspections of vehicles that show these deviating dynamic loads, have exposed onboard rail brakes systems that were not properly aligned and suspensions that were not correctly tuned.

Interfaces and user interaction

The system foresees logical outputs via relays (voltage-free contact) to allow activation of alarms or interfaces with train control systems. The 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 produces a “snap shot” picture of the vehicle, including its identification number.

The 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 the data storage at APT HQ and for remote system inspection and configuration.

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 system. Immediate alerts can be programmed to be sent by email or text message. Daily or monthly reporting can 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. Those generic modules are typically specific by the customer.
Figure 4 shows the graphical user interface (GUI) for the developed online system. In real time, each passing vehicle is added to the top of the list. The vehicle identification is shown and optionally a “snap shot” picture from the system camera is shown.

The online system communicates with an offline database that allows trending that can be used to refine the alert levels and safe data storage.

**The APT-WIM (Weigh in Motion) system**

Apart from the APT-WORM system, an add-on module to determine the dynamic weight was developed using the same processing unit with Digital Signal Processing (DSP). The system uses several strain gauges connected to the rail to perform a Weigh in Motion (WIM) measurement. Since the rail stress/strain is directly related to the weight, 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 (e.g. a Unimog road/rail vehicle). The APT-WIM system can be installed independently or in combination with the WORM system.
Economic benefits of the APT-WORM system

Depending on the configuration of the wheelsets (use of wheel rims, solid wheels, ...), the number of axles passing over the monitoring system and the current 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 lifetime of the wheels. It does not consider the secondary gains such as increased passenger comfort, decreased wear of the track infrastructure and reduced noise and vibration emissions.

The life expectancy of wheels at De Lijn is mainly determined by the maximum amount of metal that can be removed during wheel truing. Up till now, wheel truing was done at fixed km intervals. The WORM system enables a switch to condition based wheel truing, which results in significant savings. By keeping vehicles without wheel defects running, the truing intervals were significantly increased. Moreover, the early detection of wheel flats and OOR (out of roundness) results in a reduction of the metal removed during wheel truing and thus an increased life expectancy.

Further references

Within the framework of the Saferail project, an installation of the WORM system is made in Antwerp, Belgium at the exit of the main tram workshop and depot of De Lijn. The monitoring system is fully operational since 2009 and successfully helps to optimize the maintenance intervals for over 65 tram vehicles. The sensors are fixed to the rails, which are embedded below street level. The small processing unit is installed in an adjacent building to the track.

After the successful installation in Antwerp, a second installation of the system was realized in 2010 in the light rail network of De Lijn along the Belgian Coast (figure 8), this time for ballasted track and also including a WIM (Weigh in Motion) module coupled to the system. Several other installations followed in 2011 on tramline extension projects built within PPP contracts where the monitoring systems turned out to be of particular interest to the track owners (the contractors and their banks) (figure 9). Another WORM system was installed on Line 139 of the Infrabel network near Leuven to specifically monitor the condition and impacts from wheelset of freight trains on the track infrastructure. More installations both on the tram and metro network of MIVB/STIB in Brussels are scheduled for 2012.
Apart from optimizing wheelset maintenance, the same APT-WORM installations were made in Manila (The Philippines) and the USA to stop or slow down vehicles that cause unacceptable impacts to the track infrastructure.

**Outlooks**

Plug-in modules for wheel diameter measurement and flange thickness/height, without having to measure the complete wheel profile are currently in test. The modular approach allows customers to design a wheelset inspection based on their individual needs and budgets.

**Conclusions**

Within the FP7 Research Project “Saferail”, co-funded by the European Commission, APT, in cooperation with the Flemish Public Transport Company De Lijn (Belgium), developed an innovative low cost monitoring system specifically for light rail operators. The wayside monitoring system is based on the measurement of the vibrations generated by the passing wheels. Detailed signal analysis enables the detection of various anomalies related to the wheelset such as wheel flats, wheel-out-of-roundness and other deviations such as problems with suspension, bearings, ...

Early detection of wheel flats combined with appropriate corrective action not only contributes to lower track stresses and wear, but also to longer wheel life, making the installation pay for itself in a very short period. De Lijn has installed two such wayside monitoring systems in its network: one at the exit of a tram workshop in Antwerp, the other one on the line along the Belgian coast. The latter also includes a vehicle weigh-in-motion add-on. Several other installations in Antwerp, Brussels and Leuven are described in this article. Apart from the defect detection, the system quantifies the dynamic impact of the vehicle on the track, allowing trending over a longer period and a better organization of the maintenance intervals.