Condition Monitoring of a Light Rail Vehicle—From Concept to Implementation

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ABSTRACT

Condition monitoring and fault detection systems are now becoming increasingly important in rail vehicles maintenance and operation, ensuring safety and reliability improvement. Up to now light rail vehicles were not the main target for this trend, because of low operation speed and lower safety factors. Nevertheless public transport operators begin to pay a closer attention to the condition monitoring of tramways, in order to reduce maintenance cost and increase safety and ride comfort for passengers, which is a very important task for public transport competitiveness in XXI century.

Responding to the needs of the industry, a condition monitoring system for light rail vehicles and track was designed, built and tested in normal tramway operation. All important system requirements were developed on the base of present state and knowledge analysis, followed by many numerical simulations. The paper describes the system architecture, as well as the monitoring concept and the final implementation phase.

INTRODUCTION

Light rail systems have now their great return in many European cities – being a contest to passenger cars. According to UITP (Union Internationale des Transports Publics – International Association of Public Transport) there are more than 400 passenger transportation systems in over 50 countries in all continents, and more than 100 systems are being planned in the nearest future. World market of tramway production is estimated to 3.8 billion euros and the annual growth rate is expected to achieve more than 3.7 percent [1].

This increasing trend requires suitable operation and maintenance standards for both vehicle and track. Nevertheless it appears, that in Poland the average age of tramways is still much more than 30 years. Despite the continuous investment on rolling stock,

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there are no commonly used technical state monitoring systems for the mechanical part of the tramway. Consequently the light rail transit sector frequently relies on practices developed primarily for heavy rail transit, that are not necessarily well suited for tramway systems.

A similar situation concerns the infrastructure – from 1356 km of tramway track, 1000 km needs renovation [1]. Despite, tramway operators do not perform any regular or advanced track state monitoring.

In the figure above, we can see all unplanned tram stoppings in Poznań (Poland) in 2009.

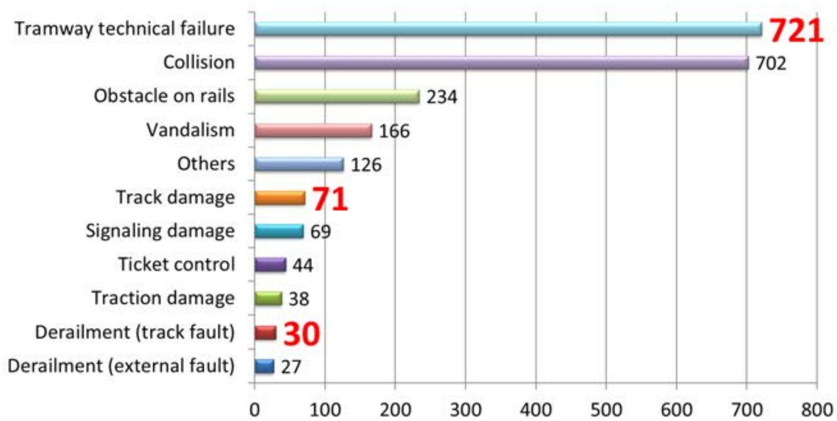

Figure 1. Causes of unplanned trams stoppings in Poznan, POLAND (2009).

From the figure above we can clearly see, that at least two time per day a tram is stopped due to technical failure or track damage. This causes serious disruptions of city traffic and generates high operating costs.

To ensure the high quality of travelling in the city, it could be very important to perform the on-line monitoring of the selected vehicle and track parameters related to the ride safety and quality, in order to predict a suitable maintenance schedule or simply to adjust the operational speed limit to the actual wear of the track.

Responding to these needs, a technical state monitoring system of light rail vehicle and track is now being developed within a framework of a research project MONIT, as a complex solution for monitoring the technical condition of main vehicle mechanical systems and components as well as for the qualitative assessment of the light rail track condition.

GENERAL CONCEPT OF THE MONITORING SYSTEM

The system is based on a dispersed network of sensors installed on the vehicle along with the data acquisition unit and a data server with the application of analysis and management of diagnostic data.

The monitoring process is realized on and from the vehicle, during its normal operation. The condition monitoring is based mainly on the acceleration signal analysis and all events are evaluated qualitatively. The general system overview is presented in fig. 2.

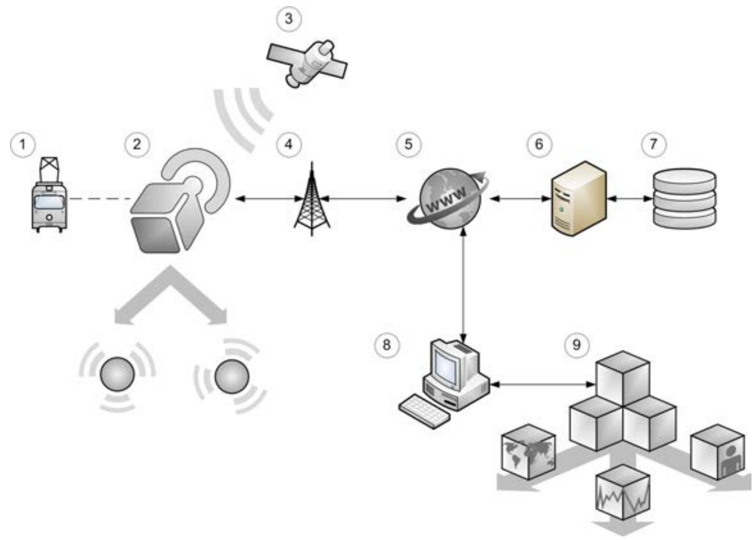

Figure 2. Condition monitoring system for light rail vehicle and track.

In the case of a vehicle, the presented system will allow the following analysis:

- assessment of the wear of running gear elements
- immediate detection of faults in the vehicle suspension elements
- dynamic adjustment of the vehicle maintenance to the actual condition of the vehicle
- complex fleet management including the current condition of the vehicles
- monitoring of ride safety and comfort
- life cycle assessment of vehicles including a history of events and trends in vehicle wear

In the case of the rail infrastructure, the system will allow:

- monitoring the main sections of infrastructure, increasing operational safety of the whole transportation system
- immediate detection of faults (cracks, weaken, flats, etc.)
- dynamic adjustment of speed limits depending on the current technical state of the given track section (including switches and crossings),
- life cycle costs assessment of the selected track section, including a history of events and trends of consumption

The modern approach is the use of smart sensor networks, which can not only collect data, but also perform distributed data processing and filter out unnecessary information before submitting it to system operator. Such distributed approach allows to increase the computing power across the network while optimizing the volume of data that is transferred between nodes. As the computations take place in sensor units it is also possible to simplify the design of data acquisition unit which would be responsible mostly for gathering data.

SIMULATION PHASE

All system requirements were developed on the base of the present state and knowledge analysis (e.g. [2÷5]), followed by many numerical simulations for different light rail vehicles types with selected faults cases, under different ride parameters, such as speed, vehicle load, track type etc.

Mathematical models of the vehicles tested during simulations are low-frequency models with the vibration range up to 30 Hz approximately, slightly different from typical rail vehicles models, presented in e.g. [6]. It is due to some differences in light rail vehicles construction compared to classic rail vehicles. After validating main model characteristics, many simulations were performed, in order to determine suitable measures for each selected vehicle and track fault - including e.g. suspension wear or wheel polygonization.

For each of tens simulation cases, selected measures were calculated from the signal of each 36 numerical sensors located in different locations on a tested vehicle. A sample 3D graph is presented in fig. 3 and represents relative values of selected measures for the right secondary damper fault simulation (represented as a damping deviation from the nominal value). The vehicle speed in this case is about 18 km/h.

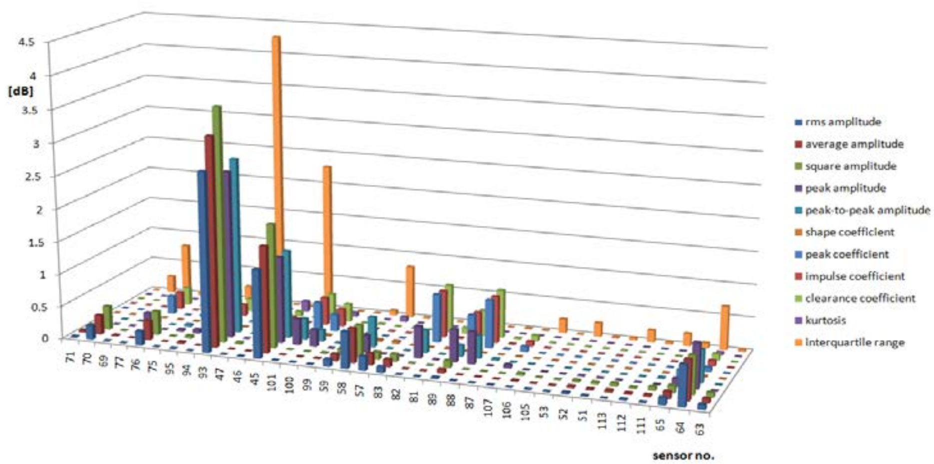

Figure 3. Selected measures relative values due to secondary damper fault.

Analyzing the graph above we can clearly assume, that for a given sensor location (e.g. sensor no. 93 and 45, which are sensors located in the middle and on the right side of a bogie frame), some measures are better than others for the condition monitoring of a light rail vehicle suspension (in this case RMS, average and square amplitude, as well as the shape coefficient).

Similar simulations were also performed for track wear, on the base of the mathematical models created for each wear scenario. An example of such a model, representing track corrugation, is presented in figure 4.

Analyzing the graph we can clearly assume, that for this kind of track irregularities the best sensors are no. 1÷6 (first wheelset, left and right side) and 19÷24 (second wheelset, left and right side). It can also be clearly seen that the best measures for this wear scenario are: RMS, average and square amplitude. The calculations were also determined sensitivity factor measures to change the technical condition of the test object. It helps to select the best diagnostics parameters.

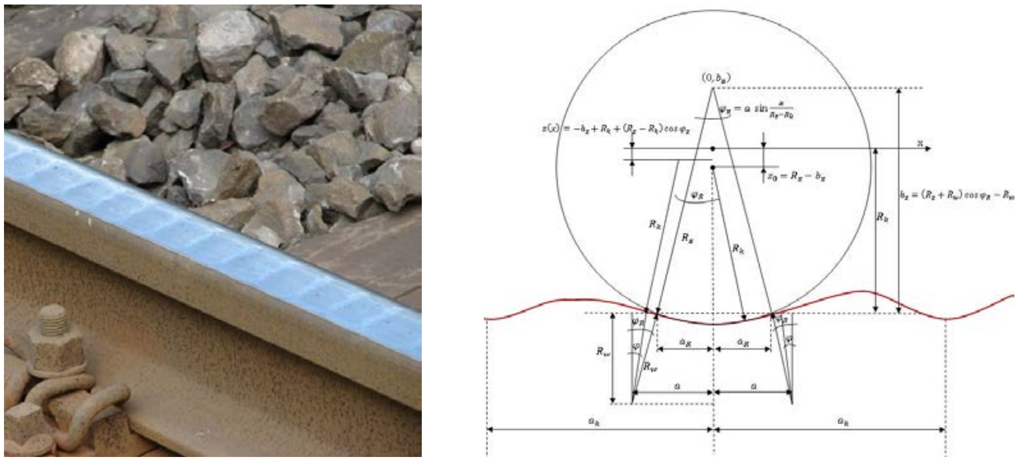

Figure 4. Rail corrugation example and its approach in numerical simulation.

A sample 3D graph for this track wear scenario is presented in fig. 5, representing relative values of selected measures. The vehicle speed in this case is about 60 km/h.

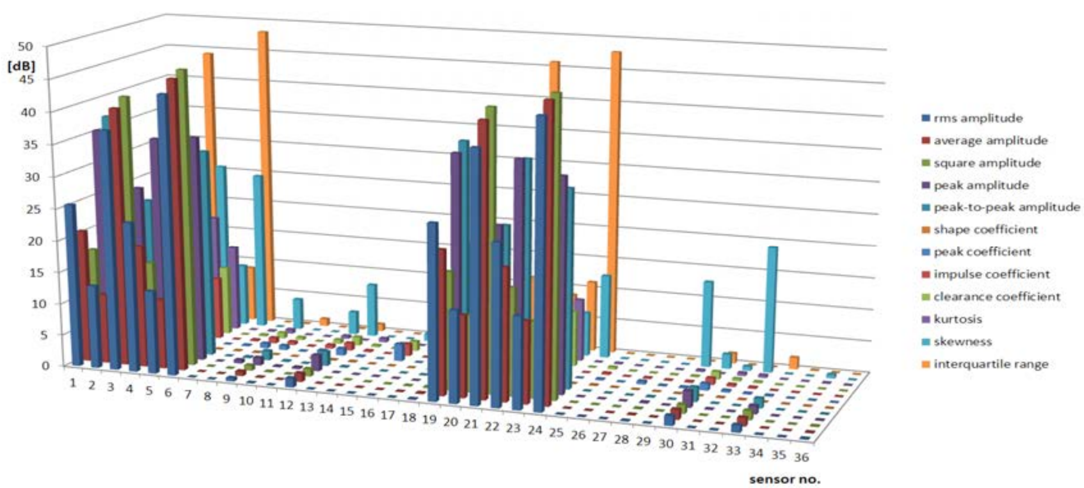

Figure 5. Selected measures relative values during a simulation on a corrugated track.

On the base of the simulation results, optimal sensors location on the vehicle was chosen:

- for vehicle monitoring: accelerometers on the bogie frame (on both side) and carbody (above each bogie)
- for track monitoring: accelerometers on both axleboxes of the first wheelset and inclinometers on all axles of the first bogie.

MONITORING PROCESS

The condition monitoring process is realized in normal operation, on two different levels, called parent loop and conditional loop. The parent loop realizes the continuous monitoring of the selected processes and is mainly used in track condition monitoring. The conditional loop realize the monitoring only while the relevant criteria are met – e.g. monitoring at the selected speed and/or on the selected track section. This loop is used mainly for the vehicle condition monitoring, especially for the suspension wear and other general vehicle parameters, like comfort and stability.

All loops are realized under different ride conditions, depending on operator's requirement. From each sensor located on the vehicle, selected measures are calculated (e. g. RMS, average and square amplitude, standard deviation, skewness, kurtosis, shape, impulse and clearance coefficients, interquartile range, Pearson's correlation coefficient, intraclass correlation coefficient, concordance correlation coefficient, etc.), and compared to the nominal values, existing regulation concerning selected parameter and/or previous measures from the same sensor in the past.

SYSTEM IMPLEMENTATION

The complete system was build and mounted on a testing tramway, which was a wagon type 105N. Sensors were placed in several positions on the vehicle - two accelerometers were attached to axleboxes of first wheelset, two consecutive devices were placed directly on bogie frame and one the vehicle carbody. Inclinometers were mounted in the middle of wheelsets axles. Sensor network also consist of a single environment condition sensing device, that provides the information about the temperature and relative humidity at with the experiment takes place. The vehicle is also equipped with a communication module and positioning system, in order to transmit all necessary data to the server unit, including vehicle speed and position.

The testing tramway, equipped with the prototype of the system, was passed in normal operation in Poznań (POLAND). The monitoring system collects selected data (based on statistic measures) from sensors and generates a local diagnosis only in strictly defined conditions of the vehicle. Information from all sensors is sent to an external server.

The server software is connected to the user via the client application (fig. 6), designed especially for this system. This application is used mainly as a fronted for the database, and a control panel for the vehicle (master sensor), using request-response and event based protocol. It is capable of handling historical data (downloaded from the database) and dynamic data, retransmitted by the server in semi real time (there is a transmission delay) from the master sensor. All data can be viewed on the map or on the chart, with exceedance of the user-defined limit for each sensor.

While the monitoring system for the light trail vehicle is still in the validation phase, the track monitoring system is already successfully working in normal vehicle operation, gathering data from the wheelset of the first bogie. In the lower-right corner of the application presented in fig. 6, selected track sections are presented, with the axlebox RMS vertical accelerations exceeding a given limit value.

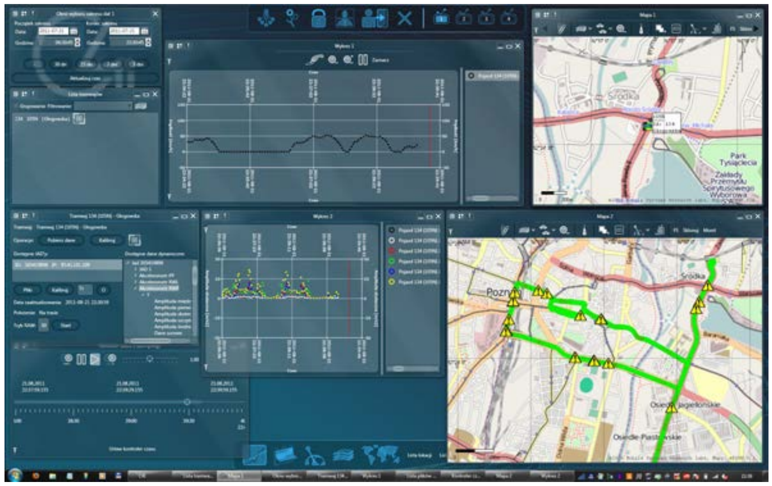

Figure 6. Graphical User Interface of the client application.

If we analyze the track condition at each "critical" point on the above presented map, we can find some very important track failures, e.g. rail cracks or vertical/horizontal deformations. Selected measures are in general not sensitive to switches and crossings, but only for different track wear cases. Two examples of rail cracks, localized by the monitoring system in Poznan (PL), are presented on fig. 7.

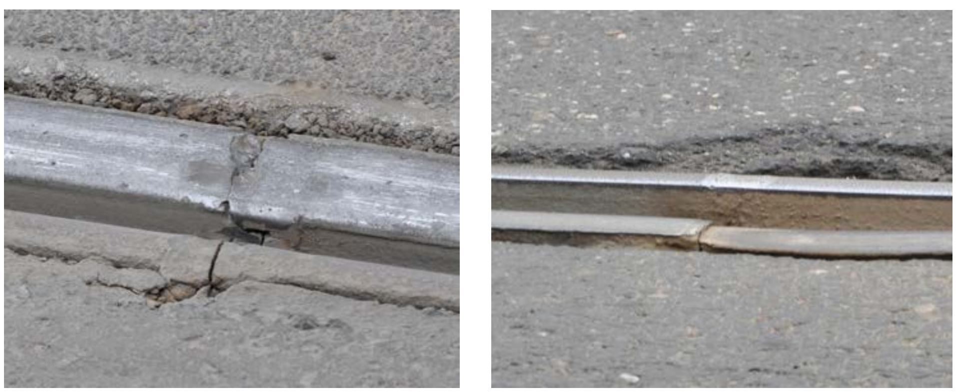

Figure 7. Exemplary rail cracks localized by the track condition monitoring system.

By the similar way, for each vehicle we can visualize all track sections with the given ride comfort factor exceedance, as well as ride stability or the derailment factor.

SUMMARY

Presented condition monitoring system of a light rail vehicle and track is a modern, complex solution for monitoring the technical condition of main vehicle mechanical systems and components as well as for the qualitative assessment of the light rail track infrastructure. Results obtained from the monitoring system can be very useful both for vehicle operators, traffic administrators or even vehicle producers.

User-friendly software allows an on-line monitoring of all vehicles and track sections, making the fleet management easier and enabling dynamic scoping repair and optimal planning of infrastructure repairs and modernizations.

The operator can observe ride comfort, stability of ride and other indexes (e.g. wheel/rail wearing) for all vehicles with immediate detection of faults and the dynamic adjustment of the vehicle maintenance to the actual condition of the vehicle. Furthermore, the analysis of the axlebox acceleration gives us the clear information about the track wear. We increase in this way the operational safety of the whole transportation system, because of the immediate detection of faults in the track. Taking those results into consideration, we can perform the dynamic adjustment of speed limits depending on the current technical state of the given track section. By comparing such a results from a given period of time, we can perform a life cycle assessment of vehicles or track sections including a history of events and trends in vehicle/track wear. All of these benefits consist of minimizing the operating costs of the transport system while increasing occupant safety.

The system is designed for use on all trams operated by municipal transport companies and in the future can become a standard feature of every new tram.

ACKNOWLEDGMENT

All presented work is realized within the framework of a research Project - „Monitoring of Technical State of Construction and Evaluation of its Lifespan" within the Innovative Economy Operational Programme, Measure 1.1 Support for scientific research for establishment of a knowledge – based economy, Sub-measure 1.1.2 Strategic programmes of scientific research and development works.

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