Tram wheel geometry monitoring system

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Abstract

Tram wheels need to be checked regularly, so when the wear reaches certain limits, the treads either have to be reprofiled to the correct shape or the wheels have to be replaced. This paper presents the autonomous wheel condition monitoring system for trams, whose employment has been the source of significant savings on wheel reprofiling and has reduced the noise level generated by trams. The measurement data is processed by a computer at the track side and transferred by wireless link to a database in a control room. Diagnostic and reporting software on the control room computer provides an interface for the display of the measured data analysis. If a wheel flat is detected, an alarm message is displayed advising the severity of the wheel defect and the recommended course of action. Exceedence reports are generated when the wheel flat exceeding the threshold value is detected. These reports give records of all wheel impacts and their position within the train. They include a graphical output showing the train, highlighting wheel defects. The experience collected using the system proves that keeping the limiting wheel dimensions without tolerance limits has eliminated tram derailments due to the wrong wheel geometry. Using the system makes it possible to forecast precisely the wheel tread as a function of its mileage between repairs, with the possibility of updating the information. The regular measurements allow forecasting of wheel tread needs, which is very important with the long lead times for them. The detailed information about the wheel profiles makes the material saving reprofiling on the wheel lathe possible. All wheel monitoring data is stored in the database which gives the possibility of extensive diagnostic analyses and reporting.

Keywords: wheel flats, build-up, monitoring, reprofiling, wheel geometry.

WIT Transactions on The Built Environment, Vol 89,© 2006 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/UT060401

1 Introduction

Trams have turned out very convenient in limiting traffic congestion and environment pollution, inclusive noise, and also by effective inducing people to refrain from driving their cars in favour of more often using the public transport. Their average timetable speeds in Western Europe are close to 20 km/h even for the LRT systems sharing tracks with other transport forms (17.4 km/h in Grenoble; 19.2 km/h in Karlsruhe; 21.1 km/h in Strassburg; 18.4 km/h in Warsaw) - Hattori [1]. Experience shows that 20÷25% of tram passengers are people who would otherwise travel by car, which reduces the resulting noise even more [2].

One tram has the passenger carrying capacity close the capacity of three buses, from which further noise reduction results. Trams, other than buses, may use the pedestrian only areas (with the sufficient width, e.g., in city centres), which is very convenient for their passengers, not colliding with other transport means. Another urban transport means - trolleybuses - use, like trams, traction network but they can carry fewer passengers than trams, thus increasing traffic density [2].

The tram is the relatively quiet transport means, for which - apart from the increased noise emission during acceleration and braking - the characteristic noise source are the steel wheels rolling on steel rails. Limiting this noise may be beneficial for improvement of advantages of this transport means and quality of life in the urban areas. Tram communication is reliable and safe - due to introducing the diagnostic systems for detection of wheel defects, checking their geometry or flat spots. Otherwise, one should expect many hazards, like track or rolling stock damages, increased noise emission, and even accidents [3].

The shelling or spalling of wheel tread, built-up material or flat spots on wheel tread are a matter of concern to metro and tram companies because of the cost of wheels removal and, additionally, because of damage to track structure and car components that may be imparted by the wheel/rail dynamic loads due to resulting irregular wheel profiles [4]. Impact loading can affect shelling in both crack initiation and crack propagation modes, the impacts can arise from a variety of causes which can be either wheel- or rail-related. Wheel flats feature a mechanical singularity that oftentimes serve as sites for the formation of additional flats and resulting shells [4].

Characteristic causes for wheel spots development and resulting interruption to train movements are, for instance, fallen leaves; the scale of this problem is big, as a mature tree has between 10,000 and 50,000 leaves [5]. The leaves on rails are like the ice on roads, being a hard slippery layer that coats the rails and is very difficult to remove. This cover is compacted by wheels, which results in carbonizing the leaves, forming a hard, Teflon-like coating on the rails. Therefore, trains have to operate at slower speeds to ensure safety and to reduce the possibility of wheel slip and spin. The resulting risk for future spalling should be considered for all wheelsets with flats.

Another problem may be the occurrence of the excess wheel flange wear and resulting derailments happening on pointworks, especially important for bogies in the middle of the tram [6]. Damage to the infrastructure caused by wheel flats and overloaded wagons is a significant cost to tram companies. Identifying vehicles with faulty wheels leads to reducing the extent of such damage, which saves substantial costs [3].

The roundness of wheels is important, especially at higher speeds, as an eccentric wheel can cause very high loads on the wheel, axle, bearing and suspension, leading to failures [5]. Wheels damaged by skidding during braking resulting in a flat patch called a "flat" are subject to overheating which can also damage a wheel; therefore, even if wheels do not wear excessively, reprofiling to remove work-hardened metal is likely to be needed; otherwise, the martensite fragments can drop out of the wheel tread. Wheels on a bogie or wheels on a single vehicle must be reprofiled within limits compared with each other. For example, a standard set for one type of coach says that wheels in the same bogie must not vary in diameter by more than 5 mm [5]. Wheels under the same coach must not vary more than 10 mm on different bogies, while the most modern vehicles might require a tolerance as low as 3 mm. A damaged wheel should be taken out of service as quickly as possible. When reprofiling the wheels, all martensite and an additional layer of several millimetres should be machined off [1, 5-7].

Tram wheels should be reprofiled periodically up to the moment when they are fully used. Wheel flanges should be reprofiled early enough to minimize the diameter loss. This is done usually every 20,000 – 60,000 km, according to the experience acquired for the particular rolling stock type. Using economical profiles, the so called worn out ones- allowing for the tread profile characteristic for the wheel wearing out with the simultaneous restoring the flange height, is conducive to extending the wheel life. The particular wheels, excessively worn out compared to other wheels of a given tram, should have similar dimensions to other worn wheels before their reprofiling and be stored in the "worn out wheels bank", from which the wheels are collected for reprofiling.

Apart from the periodical reprofiling of wheels, their reprofiling should be carried out in case of tread defect like the flat spot or build-up of a material when this defect has a substantial size and does not get self-destroyed but maintains its size or grows. This is connected with the need to compensate wheels diameters later, i.e., in addition to their periodical reprofiling.

Certainly, the wheel management discussed above is possible only when the unit operating the trams has the under-floor lathe, which makes their turning possible without taking the wheels off from the wagon. The majority of modern depots have these machine tools. Moreover, in addition to the under-floor lathe the unit operating the trams should have the measurement equipment making to possible to detect and evaluate the wheel tread defect and flange geometry measurement, and - in more advanced designs - also measurement of the bogie geometry.

Rolling stock maintenance in good condition can be programmed in one of three ways; by mileage, by time or by conditioning monitoring. Traditionally, maintenance was carried out on a time basis, usually related to safety items like braking and wheel condition [5]. Of these three methods, condition monitoring is the most recent.

This paper presents the autonomous wheel condition monitoring system for trams, whose employment has been the source of significant savings on wheel reprofiling, improved operational safety, more reliable wheel diagnostics, reduced track wear, and reduced noise level and vibrations generated by trains.

2 Autonomous wheel tread condition monitoring system in Warsaw Trams

The measurement data is processed by the computer at the track side and transferred by wireless link to a database in a control room (Fig. 1). Diagnostic and reporting software on the control room computer provides an interface for the display of the measured data analysis. If a wheel flat or material build-up is detected then an alarm message is displayed advising the severity of the wheel defect and its history, i.e., advises the date when the defect was found first, along with the information if the defect decreases or remains unchanged. Basing on this information the staff member responsible for wheel management takes a decision about sending the tram for wheel turning reconditioning them fully. The day reports with the up-to-date information about the wheel tread condition of all trams in service assist in taking such decisions. These reports give records of all wheel impacts and their position within the train. They include a graphical output showing the train, highlighting wheel defects.

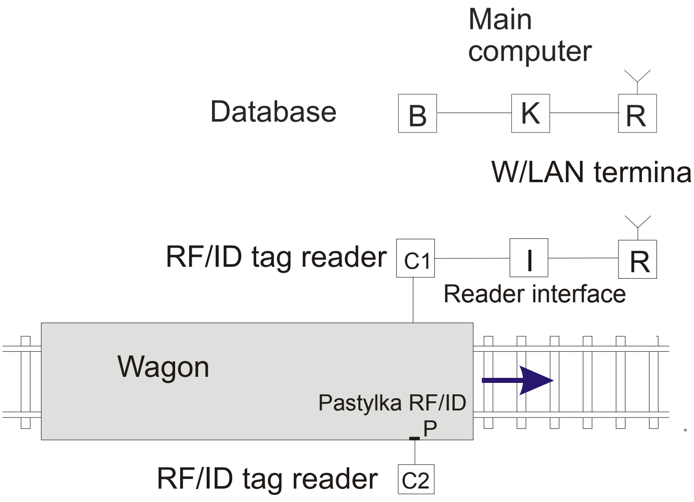

Figure 1: Schematic diagram of the wheel monitoring system.

The measurement track side computer transmits reports on individual trains following the identification of the axle within a train with the faulty wheel. These reports give records of all axles and wheels condition as well as their position within the tram. Trams are identified by the wheel monitoring system using the RF/ID system used for controlling the turnouts.

Monitoring wheel condition includes also the wheel flange profile using the manual instruments. The data from these measurements is automatically uploaded to the database, where they are analysed and archived. Measurement report includes messages about spotting the boundary values (exceeding of tolerances) and warnings about getting closer to these values. Measurement results from the wheel tread monitoring system and wheel profile control results are associated in the wheel monitoring system database. The goal of this system is assisting in carrying out the following tasks:

- carrying out control measurements of bogie geometry to determine its effect on wheel wear in operation - these measurements are made manually after their repair,
- carrying out periodical measurements of the wheel flange geometry and wheel diameter using the electronic verniers,
- collecting the data for the technically justified wheel turning on the under-floor lathe.

Carrying out these tasks is needed to:

- ensure the correct wheel-rail interaction, eliminating the danger of derailment,
- extending the wheel life between replacements,
- limiting the emission of noise and vibrations generated by tram operation,
- improvement of trip comfort.

Measurements and turning of wheels on the under-floor lathe feature the closely connected maintenance operations carried out within the framework of tram operation. The experience gathered so far indicates that the periodical measurements and turning of wheels on the under-floor lathe extend life of wheels and significantly reduce the danger of tram derailment (Gola [8]).

2.1 RF-ID system for rolling stock identification

The emitters - RF/ID tags are weatherproof and installed under the tram. The reader used in the system makes reading possible of information stored in the tag at tram speeds of up to 30 km/h. Readout of the tram ID is made automatically when the tram passes the stand and all measurement results are associated with the concrete wheels on the particular cars.

2.2 The WF system for detection of flat spots and build-up on wheel tread

The automatic measurement system makes classification of the wheel tread condition possible by detection of wheel flats and build-up on wheel tread. The software delivered with the system provides the possibility to manage information about the wagons, store information about their service, visualise the wheel shape defect classes, and also to generate their wear out reports.

The measurement system built into the track is maintenance free (Fig. 2). The measurement signals are collected and analysed by the autonomous control system. The measurement results are downloaded automatically over the wireless link by the operator’s computer system.

Figure 2: Sensors built into the track.

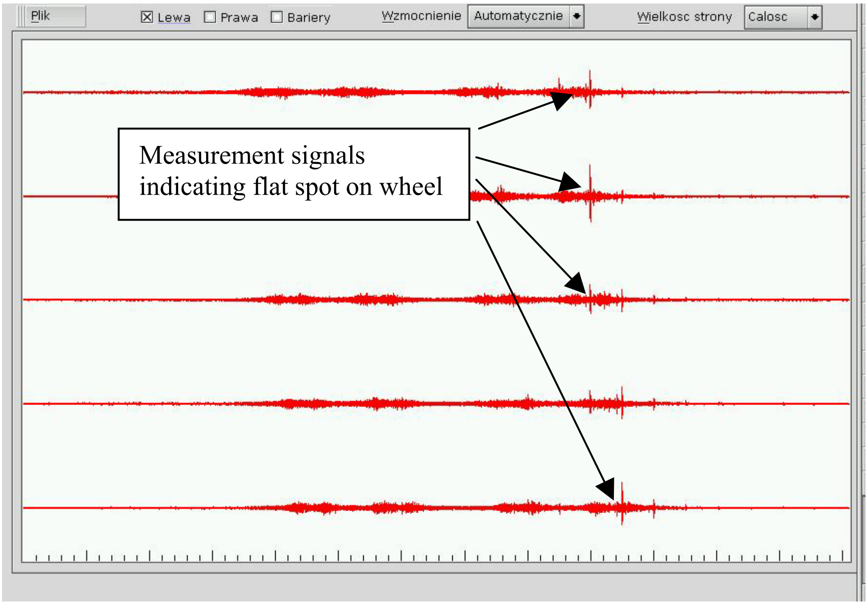

Figure 3: Exemplary measurement signals for a wheel with a flat.

The wagons are identified automatically and the measurement results are stored for specific wheels separately. The system database stores archival measurement results (Fig. 3) and other information pertaining to the operation of wheels and their maintenance - inclusive turning of bogies.

2.3 P&D rolling stock wheels monitoring system

The system was designed for storing information about profile and diameter of wheels and flat spaces and build up on their tread surface. The system makes it possible to define the required information about cars (Fig. 4), logging the distance covered by each wheel and visualisation of their wear over time (Fig. 5), as well as their repairs, inclusive generation of the wheel wear reports.

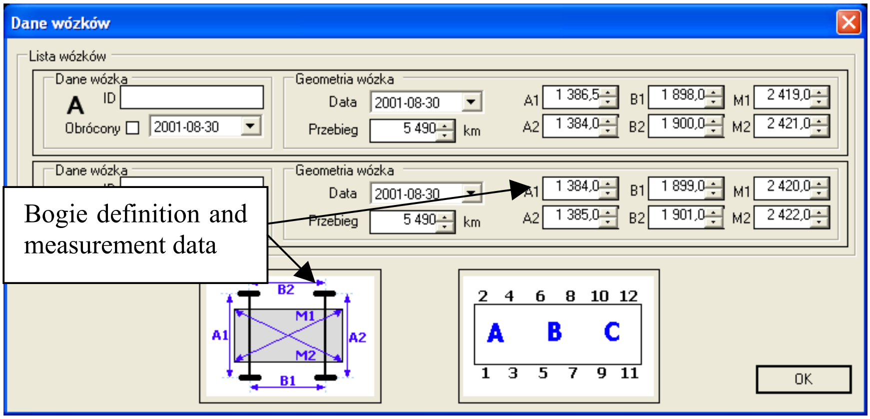

Figure 4: Definition of tram bogie.

The system integrates all measurement data collected by many units of a transport company. Measurement results of wheel geometry obtained with the portable gauges (A-B Profile Gauge, V Electronic Vernier) and with other methods are archived in a database. Moreover, information about information about the wear of the wheel diameter, occurrences of flat spots and build-up on wheel tread are stored in addition to boogie measurements results and other car service operations defined by the system user.

The wheel maintenance operations stored in the database include:

- removal of flat spots, build-up or oval,
- turning of bogie,
- measurement of wheel profile and diameter and of build-up and flat spots,
- reprofiling of wheels on the under-floor lathe,
- replacement of wheels and bogies.

The system database makes it possible to print wheel wear reports according to the user selected criteria, e.g., presenting wheel, bogie, and cars according to the following criteria:

- wheel flange height or wheel flange width or wheel diameter,
- differences of wheel flange widths in a bogie,
- differences of wheel diameters in an axle,
- tread surface condition, including:
  - current list of defects,
  - list of cars with no actual measurements,
  - car condition report,
  - train condition report.

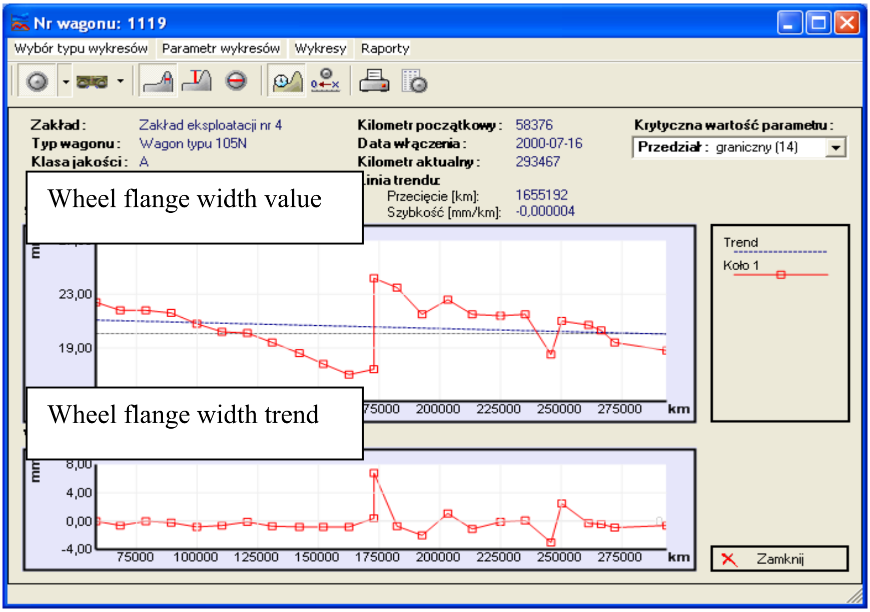

Figure 5: Exemplary change of the wheel flange width.

3 Verified implementation effects of the system on Warsaw's trams

Effective use of the periodical measurements for their diagnostic analysis calls for their previous archiving. The advantages resulting from the periodical wheel measurements and their technically justified reprofiling on the under-floor lathe include:

- Protection from exceeding the boundary wheel dimensions, eliminating the danger of derailment due to wrong wheel flange geometry. This type of derailments has been entirely eliminated.
- Possibility of the detailed wheel wear forecasting by determining the wheel tread wear growth versus its mileage, with the possibility of corrections. Periodical measurements make it possible to forecast demand for tyres. This is very important with the six months or longer delivery lead time.

- Possibility of the material saving machining of wheels on the under-floor lathe by preparing the tram for this operation. Preparing the tram consists in analysis of wheel dimensions before turning and in the eventual emergency replacement of single wheels worn out in a way significantly different from wear of other wheels; the replacement wheels are selected using the wheel monitoring system database. Therefore, during machining on a lathe to equalize the diameters of all tram wheels, so that their difference stays within the tolerances, it is possible to reduce the required depth of cutting.
- Reprofiling of wheels up to the moment when the whole tread is used up.
- Less noise and vibrations add to environment protection.

4 Conclusions

Effects obtained by the wheel management using the presented system are as follows (Gola [8]):

- Derailments due to wrong wheel geometry have been eliminated.
- Wheel tread life, measured by mileage between wheel replacements, has been extended from 80,000–90,000 km to 200,000–250,000 km for wheels with dimensions new/worn out 650/600 mm.
- Ride quality has been improved.
- Deformation of wheel treads has been limited, which resulted in limiting the emission of noise and vibrations.

Further aims are to:

- Furnish all depots with the automatic wheel monitoring systems with the computer measurement data analysis and choosing trams for wheel turning on the under-floor lathe restoring the correct geometry of wheel tread.
- Successively furnish the depots with the automatic wheel flange and diameter, as well as car bogie geometry, measurement stands, which would replace the electronic verniers and wheel flange profile gauges in use now.

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