



CETRA²⁰¹²

2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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CETRA²⁰¹²
2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

TITLE

Road and Rail Infrastructure II, Proceedings of the Conference CETRA 2012

EDITED BY

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ISBN

978-953-6272-50-1

PUBLISHED BY

Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE

minimum d.o.o.
Katarina Zlatec · Matej Korlaet

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600

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ENSURING SAFETY OF OPERATION BY AUTOMATIC MEASUREMENT OF ROLLING STOCK WHEELS GEOMETRY

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Abstract

Safe rolling stock operation calls for objective and reliable monitoring of wheel wear which is an important factor affecting passengers' and cargo transportation safety. Wheel wear developing continuously during operation includes deterioration of the wheel flange cross sectional profile and reduction of wheels' diameters, which have to be analysed for all wheels in a bogie, and coach. Wheel profile and diameter have to be inspected regularly, as their uncontrolled change with time would pose threat to safety of train operation as, for instance flange angle and root radius are the variables that have a significant effect on the possibility of derailment. In any case change of the wheel profile may lead to the increased rolling contact fatigue which can have expensive and dangerous consequences. Another important issue is the out-of-roundness error, very important especially for the high-speed trains. The wheel wear process is more intensive than the track and turnouts degradation.

Polish fast train operator InterCity decided to monitor its entire fleet of coaches and the relevant measurement system was required, so the laser system was developed by GRAW (Poland) to measure automatically wheel sets on all coaches using the machine vision technology. The system has been designed to perform the automatic, contactless measurement and monitoring of flange height and thickness, Qr parameter, wheel diameters on rail vehicle wheel sets, as well as for bogie geometry control. Moreover, the system can identify coaches from their RFID tags, and based on the wheel history, it can recommend the pre-emptive maintenance operations. The paper presents the measurement system principle and measurement results, as well as the independent portable devices used to verify its readings.

Keywords: tram, track, vibrations, urban areas, environmental protection

1 Introduction

During wheelset operation, its wheels are subject to wear and when the worn profiles reach one of the limit values defined by international standards [1], the wheels have to be reprofiled. This continuous wear of the vehicles' wheels is an important factor affecting safety of train operation. The problem has to be analysed from two, conflicting sometimes, points of view: the impact of trains operation on the infrastructure condition, and the damage on vehicles caused by the infrastructure condition [2]. Having that in mind one has to analyse these factors affecting heavily the life cycle costs of the railway networks. The goals of many projects (like, e.g., AWARE – ReliABle Prediction of the WeAr of Railway WhEels) and new developments are finding the methods to reduce the operation and maintenance costs, by increasing the life cycle of both vehicles and tracks, however, with increasing the speed, safety and ride comfort of the trains [3].

Apart from the safety issues, economy is also becoming the increasingly important issue. It is known that some wheelsets may require reprofiling after only 80.000 km of service, while

others can safely operate for more than 400.000 km in similar conditions without need such maintenance procedure. It has to be also born in in mind that the railway wheels can be usually reprofiled not more than 3 or 4 times and that wheelset replacement is very expensive [3, 4]. One has to take into account also that the premature wheel wear usually results in the excessive wear of the rails condition deterioration. The rolling stock operators' losses include both the wheel reprofiling or wheelset replacement costs and also a cost resulting from the damage done to the permanent way, which they have to incur either as a penalty paid for the bad condition of wheels of their fleet, or by spending more money on the permanent way repairs should it be their property, like it happens for metro or some tram companies.

The process of the loss of relatively large (up to 5mm) pieces of metal from the wheel tread surface is caused by stresses generated by rolling contact of the wheel with the rail. To make the process more complex, the rolling contact stresses are always affected by other factors also. These other factors finally result in differentiation of the wheel surface damage by shelling (initiated by contact fatigue) and spalling (initiated by thermal cracking) [5].

Therefore the wheel wear developing during operation includes deterioration of cross sectional profile of the wheel flange, diameter reduction, and which is especially important – this reduction has to be analysed for all wheels in a bogie, and for both wheels of a wheelset. Another important issue is the out-of-roundness error, very important especially for the high-speed trains. This process is affected by track geometry and condition, as well as by such rolling stock operation characteristics like operation velocity, load, and overall technical condition of the coaches and locomotives. The wheel wear process is more intensive than the track and turnouts degradation [6÷8].

Wheel profile and diameter have to be inspected regularly, their change with time may pose threat to safety of train operation as, for instance flange angle and root radius are the variables that have a significant effect on the possibility of derailment. In any case change of the wheel profile may lead to the increased rolling contact fatigue which can have expensive and dangerous consequences [9÷10].

Therefore, monitoring wheel wear is crucial for ensuring the safe fast trains operation. Polish fast train operator InterCity decided to monitor its entire fleet of coaches and the relevant measurement system was required. GRAW developed the laser system to measure and detect automatically wheelset defects on all coaches being unique in that the profile/diameter modules take many laser images of the wheels from which all measurements are taken and statistical analysis is performed [11÷12]. The system can identify coaches from their RFID tags, based on the wheel history it can enable the pre-emptive maintenance to be conducted having the relevant defect thresholds set.

The system has been designed to perform the automatic, contactless measurement and monitoring of flange height and thickness, Qr parameter, wheel diameters on rail vehicle wheelsets, as well as for bogie geometry control. Additionally, measurement of distance inner faces is carried out. The system operation is unattended and can be remotely monitored..

2 System design

The system (Fig. 1) has been designed to be installed at the entrance to the depot for the automatic non-contact measurement of bogies, as well as wheel profile and diameter of coaches moving at speeds of up to 20 km/h. The system is suitable for operating at temperatures from -30 to +60°C, with humidity of up to 98%.



Figure 1 Train entering the measurement system at Intercity Depot in Warsaw

All measurement system modules are fixed to the carrying frame, thermally insulated to minimise the effect of the changing ambient temperature. The cameras, along with the lasers are built into the housings into which the conditioned air is continuously blown in to keep them in stable conditions and to protect from dust and water.

The measurement procedure is fully autonomous and does not call for any operator involvement, as the train is detected by the ultrasonic sensor at the entry and the measurement data are stored in the local database, whose contents is automatically uploaded to the host computer at the supervisory level system. All successive axles are detected by axle sensors (Fig. 2). The particular coaches are identified using the RF/ID technique, so all measurement readings can be assigned to particular wheels for further analysis and reporting.

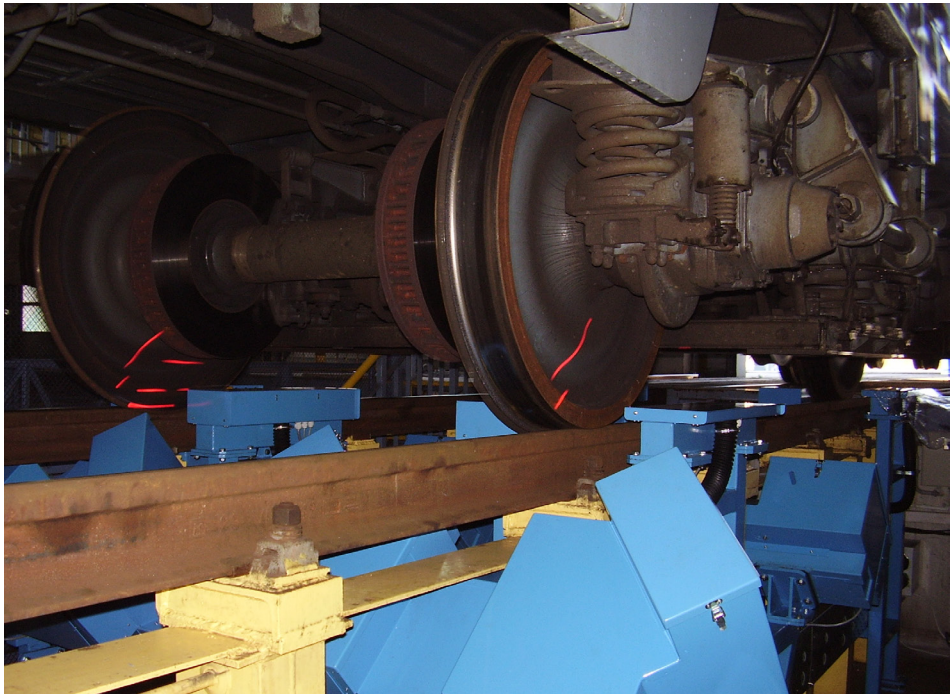


Figure 2 Wheelset passing the measurement zone

The system consists of three main subsystems: wheel profile measurement, wheel diameter measurement, bogie geometry measurement. All measurement data is sent to the respective measurement computer and after processing the wheel data is sent to the local database. The measurement computers with the QNX real time operating system are autonomous and may operate independently from the host computer. Once the host computer is switched on all data from the local system database is automatically transferred to the main SQL database on the system operator's host computer running on MS Windows platform.

The wheel measurement database has built in reporting features making it possible to produce tabular and graphical printouts. The measurement results for coaches are stored in the databases which makes monitoring possible of the progressing degradation of the wheel profile and diameter. These reports are used for planning of repairs of coaches. For those coaches which do not have the RF/ID tags alarm signals are generated when the wheel is detected with the excessive profile wear parameter value.

3 Measurement principle

The goal was to develop the system has to carry out all measurements with the contactless method. Another requirement was the unattended operation and the maintenance reduced to minimum. The laser based measurement system (Fig. 3) was developed using experience gathered in similar previous projects involving wheelset measurements [12÷15].

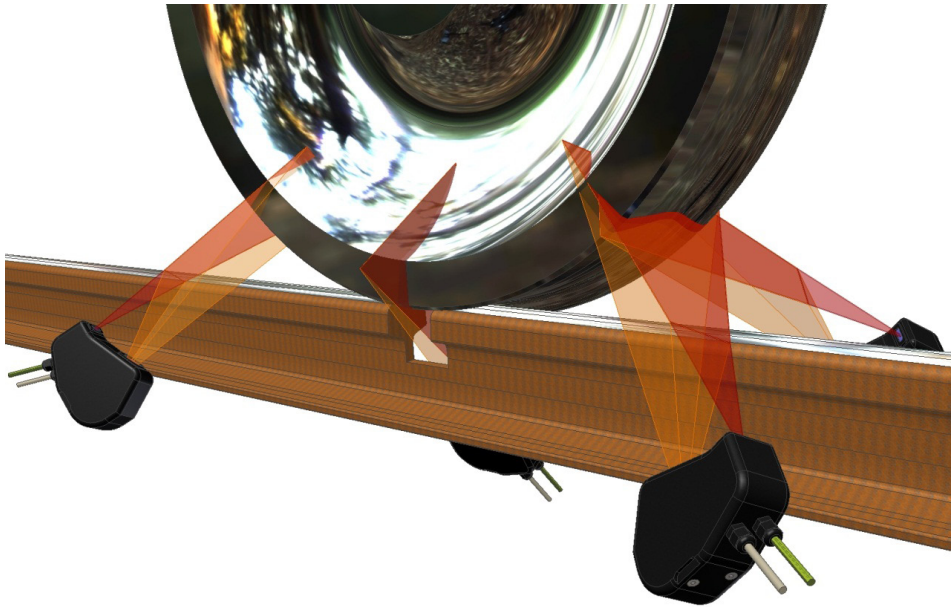


Figure 3 Configuration of cameras and structured light sources for one wheel

The system is based on the industrial grade implementation of the light sectioning principle. The system has a modular design, so that only the selected subsystems may be installed in future installations.

3.1 Justification of the measurement results

As the non-contact measurement method was used, one had to make the accuracy and repeatability tests to prove correctness of the readings and also to fine tune the system. The tests were made on two coaches whose wheels were replaced on one coach, and on another one on which they were reprofiled on the underfloor lathe.

The reference contact measurements for the system were made with the A-B Profile Gauge and WM-3 Wheel Diameter Gauge made by GRAW [16÷18]. Both of these instruments were calibrated and checked on the templates before being used for the reference measurements. Therefore the wheels were measured both using the contact manual devices and later with the laser non-contact system.

Wheel profile measurements were made immediately before measurements carried out with the laser system. Profiles of all wheels were measured in two locations each that were available from the inspection pit without the need to dismount the wheel sets. The wheel diameter reference measurements were made after the measurements carried out by the laser system. The coaches were lifted which made it possible to make many diameter measurements over the entire wheel perimeter. The minimum number of measurements for one wheel was from 12 to 19.

The coaches were marshalled with the locomotive forming a test train. The measurements on the laser system were made in two series with 10 passes in each series. The train was turned before the second measurement series. This procedure made it possible to compare the readings between the independent measurement results carried out by the independent measurement module located under each rail.

3.2 Wheel profile measurement results

Wheel wear parameters (Sh, Sw, Qr) were compared with the measurements made with the A-B Wheel Profile Gauge. The maximum differences between the averaged values measured by the laser system and contact measurement were: for flange height 0.3 mm, flange width: 0.2 mm, and Qr: 0.2 mm, and the standard deviation values are less than 0.1 mm (Table 1). The system collects the wheel geometry information which makes it possible to monitor its continuing wear.

Table 1 Laser system measuring range – wheel profile

Parameter	Measurement range [mm]	Standard deviation [mm]
Sh	23÷38	0.08
Sw	20÷35	0.08
Qr	6÷12	0.10

3.3 Wheel diameter measurement results

Wheel diameter measurements were evaluated in two ways: by the standard deviation yielding information about the system repeatability and by comparison with the measurements carried out with the WM-3 gauge, which made assessment of the calibration errors possible. The maximum standard deviation calculated independently for each measurement module did not exceed 0.2 mm. It should be noted that this is the same value as for the WM-3 gauge. Analysing this result one has to take into account that wheel measurements were taken by the system in many different locations on the wheel perimeter – just like measurements taken with the wheel diameter gauge, which means that wheel shape errors were detected also.

Table 2 Laser system measuring range – wheel diameter

Parameter	Nominal value [mm]	Standard deviation [mm]
Diameter	840÷950	0.05
Parameter	Allowed value [mm]	Standard deviation [mm]
Difference of diameters	0.5	0.05

3.4 Bogie geometry measurement results

Bogie geometry measurement results could not be compared with any reference measurement, as there are no other systems that might make such measurements possible. Therefore, repeatability analysis was made, taking into account turning the trains. The parameter describing the repeatability is the difference between the maximum and minimum measured values from 20 samples. The measured bogie geometrical parameters are described in Fig. 4 and in Table 3, their deviation from the nominal values is an important premise for the relevant maintenance and repair operations.

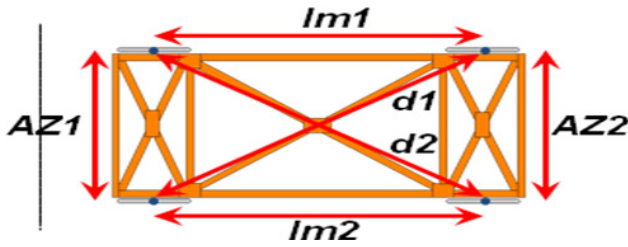


Figure 4 Exemplary bogie measurement report

Table 3 Laser system measuring range – bogie geometry

Parameter	Nominal value [mm]	Standard deviation [mm]
lm	2500÷2600	0.10
AZ	1360	0.05
d	2846÷2934	0.20

4 Exemplary measurement results of the system in service

The system provides the user with the current wheel and bogie geometry results which are the base for their maintenance and repair decisions. All measurement data are date and time stamped which makes it possible to analyse progress of their wear and detect changes of such trends that may require closer analysis. Such symptoms, studied automatically by the system diagnostic software to reveal the disadvantageous coincidences, give early warnings which may suggest certain corrective measures. This is especially important when such corrections may be carried out on wheels or bogies whose geometry is still within their relevant tolerances. This is an important feature extending greatly the system base functionality focused on detection of wheels and bogies whose geometrical parameters exceed the tolerances specified in the pertinent regulations. The user may specify their custom warning values which will make wheel geometry repair and even suggest that certain wear trends may indicate to geometrical errors of bogies.

4.1 Wheel profile measurement

The main critical criterion for deciding the immediate withdrawal of a car is detection of the excessively low Sw parameter value and/or the excessive difference of Sw parameters of the wheels in the wheel set; however, this assessment used to be done even not that long ago by visual inspection only which in many cases would not reveal the real wheel and wheel set condition. Once overlooked, the defect would lead to rapid wheel geometry deterioration which at a later time would result in huge wheel material loss during reprofiling thus cutting significantly wheel life. The average value of Sw coefficient proved to be the reliable and stable indicator of the wheel set wear (Fig.5).

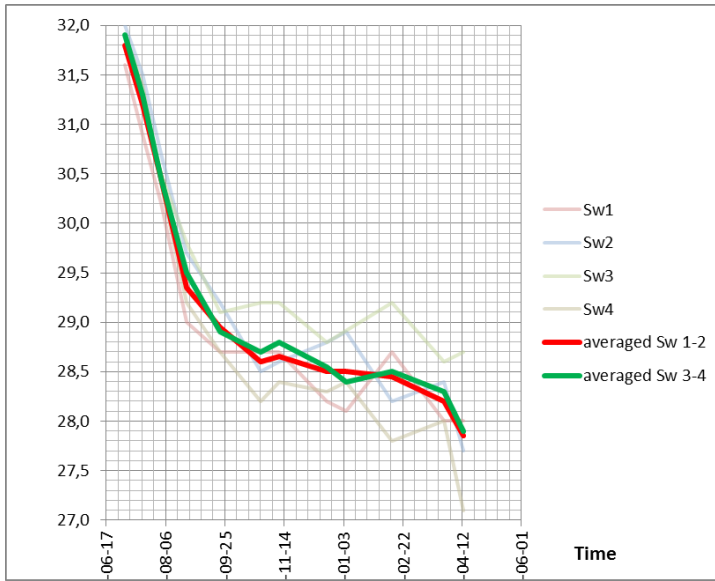


Figure 5 Sw values change between wheels (1–4) reprefiling operations for a bogie

Another important wheel geometry coefficient is Sh – related directly to wheel diameter, which is hard to measure reliably with portable instruments. Therefore, while checking the Sh values to keep them in the required tolerance range, one may also use Sh values as indication of the wheel diameter change, which may render the diameter measurement module unnecessary in certain applications. The Qr parameter easily measured with the laser system demonstrates clearly the fast initial wheel profile deterioration and maintains a steady value during the further wheel operation when no unexpected profile failures take place (Fig.6). Any disturbance of the wheel profile condition can be easily detected also from this parameter history by the measurement system diagnostic software.

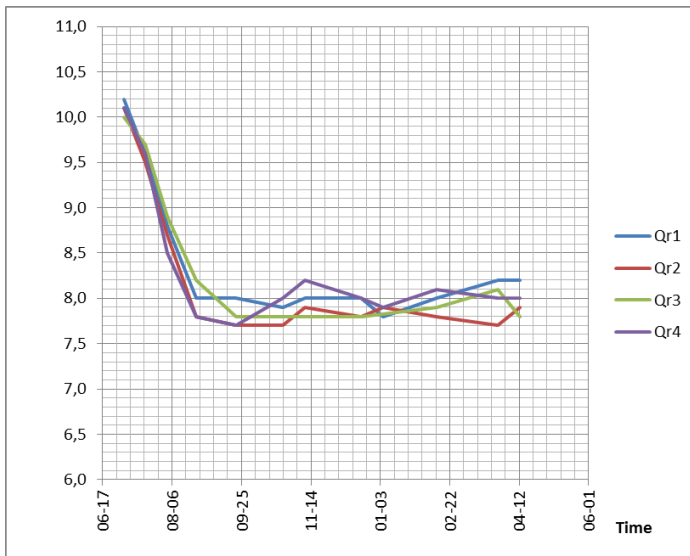


Figure 6 Qr values change between wheels (1–4) reprefiling operations for a bogie

4.2 Wheel diameter measurement

Automatic wheel diameter measurement results analysis makes it possible to verify quickly and reliably not only the particular wheel's diameter correctness but also checks if the difference of diameters of wheels on the wheel set, wheel diameters scatter in the bogies and in the coach (Fig.7). All this is done for all coaches in real time as the train passes the measurement stand. Wheel diameter can be measured for all brake design versions on various coaches.

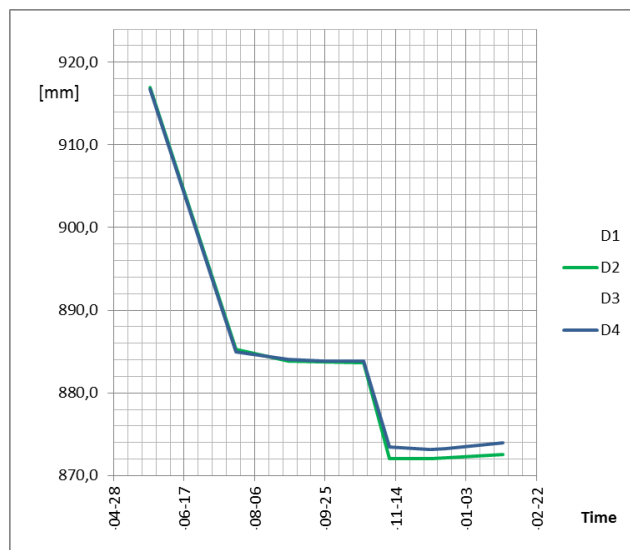


Figure 7 Diameter measurement values – it is evident how much of wheel material is lost when the wheel reprofiling is done too late

5 Conclusions

Apart from all consecutive the wheel measurement results for all supervised trains the measurement system database includes, among others, also the following data: removal of flat spots, build-up or oval, turning of bogie, measurement of wheel profile and diameter, measurement of build-up and flat spots, reprofiling of wheels on the under-floor lathe, and 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, wheel flange width, wheel diameter, differences of wheel flange widths in a bogie, differences of wheel diameters in an axle, tread surface condition, taking into account the current list of defects, list of cars with no actual measurements, car condition report, and train condition report. 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.
- 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 tires. This is very important with their 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 car for this operation 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 car wheels, so that their difference stays within the tolerances, it is possible to reduce the required depth of cutting.
- Reprofiting of wheels up to the moment when the whole tread is used up.

References

- [1] UIC 510-2, 'Trailing Stock: Wheels and Wheelsets. Conditions concerning the use of wheels of various diameters.' 2004.
- [2] Pombo, J., Ambrosio, J., Pereira, M., Lewis, R., Dwyer-Joyce, R.S., Ariauo, C. & Kuka, N.: A study on wear evaluation of railway wheels based on multibody dynamics and wear computation. *Multibody System Dynamics*, 24 (3). pp. 347-366.
- [3] Jendel T.: Prediction of wheel profile wear—comparisons with field measurements, Elsevier Science B.V, *Wear* 253 (2002) pp. 89–99,
- [4] Madejski J.: 'Laser rolling stock wheel and bogie measurement system', Proceedings of the 18th International Conference on Current Problems in Rail Vehicles ProRail'2007, Žilina, Slovak Republic, 18-21.09.2007
- [5] Semih F. K.: Investigation of wheel tread irregularities, Association of American Railroads Vehicle Track Systems Newsletter, Dec, 1989
- [6] Zhai W., Cai C., Wang Q., Lu Z., Wu X.: Dynamic effects of vehicles on tracks in the case of raising train speeds, Proceedings of the I MECH E Part F Journal of Rail and Rapid Transit, Volume 215, Number 2, 12 June 2001
- [7] Jendel T., Berg M.: Prediction of wheel profile wear methodology and verification' Proc. 17th, IAVSD Symposium - Copenhagen, 2001
- [8] Esveld C.: One procedure for optimal design of wheel profile, Proc. 1st Wheel-Rail Interface management conference - Amsterdam, 2002
- [9] Tracy R.: The benefits of unattended geometry measuring, *International Railway Journal*, 2004
- [10] Madejski J., Gola A.: Tram wheel geometry monitoring system, URBAN TRANSPORT 2006 - Twelfth International Conference on Urban Transport and the Environment in the 21st Century, Prague, Czech Republic, 2006
- [11] Madejski J., Burghardt J.: Machine vision application for cold plate width measurement, Proceedings of the 12th Scientific Conference AMME-03, Gliwice- Zakopane, 2003
- [12] Grabczyk J., Madejski J., Nowicki R., Rzepka w. & Żaba P.: Automatic Wheel geometry control in trans, International Scientific Seminar - 'Railway wheelsets: Theory, Design, Manufacturing, Operation', Katowice-Ustroń, 1995 (in Polish)
- [13] Grabczyk J., Madejski J., Molerus P.: Laser Profile Measuring Gauge, 4th International Scientific Conference 'Achievements in Mechanical and Material Engineering' AMME'95, Gliwice-Wisła, 1995
- [14] Madejski J., Grabczyk J., Sitarz M.: Requirements, method, and new instruments and measurement systems for railway wheelsets, Technical Seminar - Huta 1-Maja, Gliwice, 1996 (in Polish)
- [15] Madejski J., Grabczyk J.: Track and Rolling Stock Quality Assurance Related Tools, Computer Aided Design, Manufacture and Operation in the Railway and other Advanced Mass Transit Systems - COMPRAIL 98, Special Session on 'Safety of High Speed Trains', 2-4 September 1998, Lisbon, Portugal; further extended and published as a chapter in 'Structural Integrity and Passenger Safety' - Wessex Institute of Technology, 1999.
- [16] GRAW sp. z o.o.: User Manual – P & D Diagnostic Wheel Database, Gliwice, 2009.
- [17] GRAW sp. z o.o.: User Manual - A-B Profile Gauge, Gliwice, 2009.
- [18] GRAW sp. z o.o.: User Manual - WM-3 Wheel Diameter Gauge, Gliwice, 2010