INCREASING THE TRAFFIC SAFETY LEVEL OF ROLLING STOCK BY WHEEL CONDITION MONITORING USING AN AUTOMATED MEASURING COMPLEX

Sergii Kliuiev[1], Stanislav Semenov[1], Evgeny Mikhailov[1], Ján Dižo[2,*], Miroslav Blatnický[2], Vadym Ishchuk[2]

[1]Department of Logistics and Transport Safety, Volodymyr Dahl East Ukrainian National University, Kyiv, Ukraine
[2]Department of Transport and Handling Machines, Faculty of Mechanical Engineering, University of Zilina, Zilina, Slovak Republic

*E-mail of corresponding author: jan.dizo@fstroj.uniza.sk

Sergii Kliuiev 0000-0003-3698-9917,
Evgeni Mikhailov 0000-0002-6667-5348,
Miroslav Blatnický 0000-0003-3936-7507,
Stanislav Semenov 0000-0002-5236-4557,
Ján Dižo 0000-0001-9433-392X,
Vadym Ishchuk 0000-0003-2024-382X

Resume

The rail rolling stock undercarriage condition monitoring is proposed by using an automated measuring system, located on the railway track and measuring the specified parameters of the wheels directly, while the train is moving. Regular undercarriage condition monitoring reduces the costs of preventive maintenance of rolling stock without compromising the traffic safety. An algorithm has been developed for the operation of a special software package for visualizing and assessing monitoring data on the condition of the undercarriage of rail rolling stock. The software package consists of separate software modules that can be used independently of each other. It is possible to make short- or long-term predictions of the behavior of any of the monitored parameters using an proposed automated measuring system.

Article info

Received 12 February 2024
Accepted 4 May 2024
Online 23 May 2024

Keywords:

rolling stock
carriage part
wheel
rail
measurements
defect
measurement accuracy
traffic safety

Available online: https://doi.org/10.26552/com.C.2024.031

ISSN 1335-4205 (print version)
ISSN 2585-7878 (online version)

1 Introduction

With the increase in the speed of rail vehicles, the demands for the quality of both the track and rolling stock are growing. However, the situation in the transportation services market does not allow for a significant increase in expenses for the technical maintenance of rolling stock. Therefore, it is necessary to ensure optimal utilization of funding without compromising the safety level of transportation [1-4].

Increasing the traffic volumes and train speeds require greater attention to monitoring the condition of the rail rolling stock. To solve this problem, measuring devices are created that are located on or near the railway track and are capable to measure the necessary parameters directly while the train is moving, by their dimensions, weight and other parameters [5-8].

2 Presentation of basic materials

The operation of the wheel-rail system is associated with significant wear of both components interacting in it [9-12]. This specially applies to wheels. The parameters of wheel pairs, controlled in operation, are the distance between the inner edges of the railway wheel flanges, rolling surfaces, thickness and vertical undercut of the wheel flanges [13-14]. To ensure the high reliability, measurements of these parameters are carried out at four points on the circumference of each wheel [15-17].

Manual measurements, using special templates, are associated with significant labour costs, as well as downtime of the rolling stock. Automation makes these measurements faster. This ensures the necessary measurement accuracy.

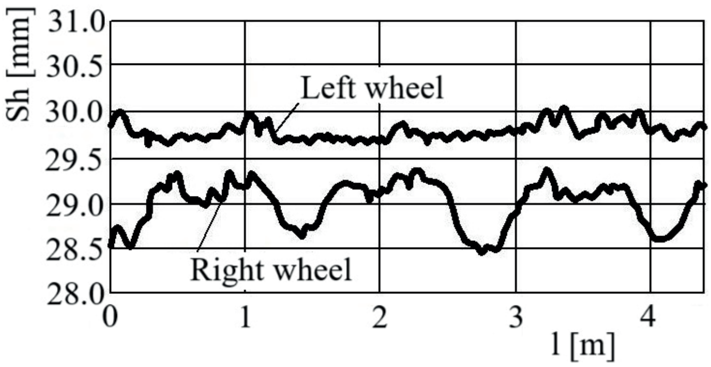

Figure 1 *Changing the flange height*

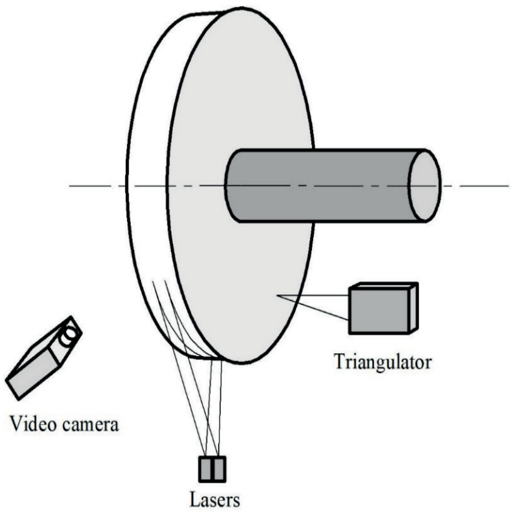

Figure 2 *Measuring the wheel diameter and the distance between the inner edges*

Monitoring wheels to detect out-of-roundness and sliders is a basic condition for ensuring the traffic safety [18-20], especially for high-speed trains. Having accepted that the wheel flange apex has a sufficiently accurate circularity and concentricity with respect to the axis of rotation, it is supposed that the deviation from the nominal wheel flange height is identical to the deviation of the rolling circle from the ideal circle and carries information about the size of non-roundness and the depth of the sliders. In the proposed automated measuring complex, to control this parameter, a measuring beam is used, the lowering of which, when pressed with the top of the flange, is counteracted by the pressure of compressed air [21-22]. When the wheel rolls, the vertical stroke of the beam is measured using an electromechanical sensor. The signal from the sensor is transmitted to the micro-processor of the module, where it is processed and recorded as a change in the beam stroke for at least one wheel revolution [23-24]. Using the curve of changes in the height of the flange per revolution, the presence of non-roundness or a slider is determined (Figure 1). The error of sliders depth, or the size of out-of-roundness measuring, do not exceed 0.2 mm.

The wheel diameter is determined by the radius of one wheel segment curvature using the laser beams. To do this (Figure 2), two lasers, with the V-shaped beams diverging in one plane, are placed beneath the wheel under the study. These rays are recorded by a digital video camera located on the side.

Images of pictures are transferred to the microprocessor module using appropriate transformation. For this process to be carried out without disturbing the scale, the transformation parameters are calibrated on a wheel segment of known diameter [25-26]. Guaranteed accuracy of the wheel diameter measurements with a range from 600 to1300 mm is 0.6 mm.

The distance between the inner edges of the wheelset wheels flanges is determined using an optical measuring system. The triangulation device used for measurements sends a laser beam to the inner edge of the wheel flange, where the beam trace is observed as a luminous point. An optical system, mounted on the side, records the location of this point. The error, when measuring the distance between the inner edges of the wheel flanges, can reach the value of 0.4 mm.

To use an automated measuring complex for other types of rail vehicles (subway cars, trams, etc.), it is necessary to select the diameter of the probing laser beam experimentally, and adapt the location of the complex measuring elements.

The change of the wheel profile is caused by its wear

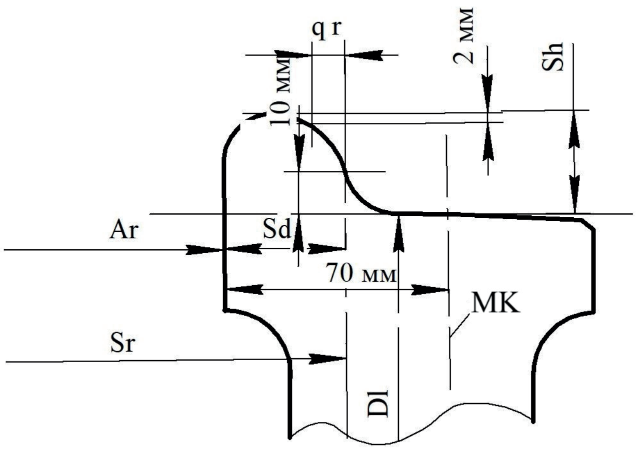

***Figure 3** Parameters of the measured wheel profile: Ar - the distance between the inner edges of the wheel flanges; Sr - track width; Sd - flange thickness; Sh - flange height; Dl - diameter of the rolling circle: MK - surface of the measuring circle; qr - transverse dimension used to calculate the amount of flange trimming*

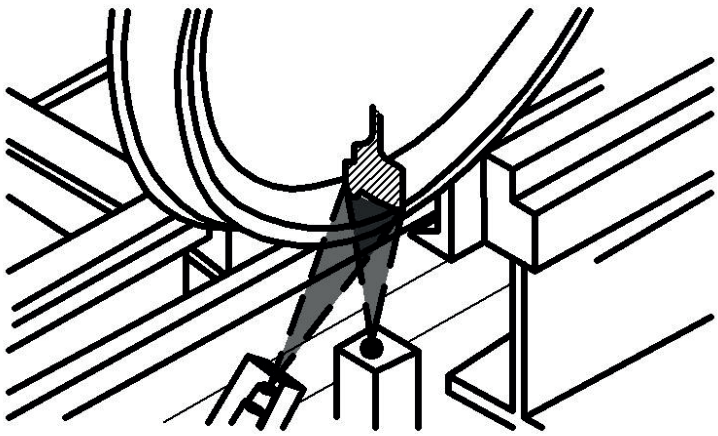

***Figure 4** Measurement of the wheel tread surface profile*

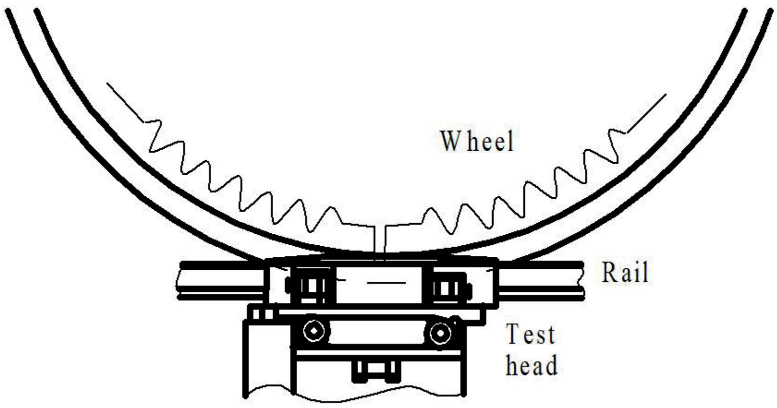

***Figure 5** Propagation of pulses in a wheel during the ultrasonic flaw detection*

due to the loss of material from the tread surface [27-30]. The quality of a wheelset is determined by the following main parameters: height and thickness of the flange, transverse size (qr) used as the basis for calculating the amount of flange trimming, the distance between the inner edges of the wheel flanges and the equivalent conicity (Figure 3).

Measurement of a wheel tread surface profile is performed using the same method as measuring its diameter (Figure 4). To do this, one laser with a flat V-shaped beam is installed below the rolling wheel such that the plane of the beam is strictly perpendicular to the direction of the wheel movement. All the specified parameters that determine the profile are measured with an accuracy of 0.2 mm. For repeated measurements of the same parameter, the accuracy is 0.1 mm.

The condition of the metal adjacent to the wheel tread is examined using ultrasonic pulses of a frequency of 400 kHz, which are sent to the wheel tread by the transceiver head. The impulse is being propagated in the wheel in the form of surface waves, which repeatedly circle the wheel in both directions (Figure 5). A defect in the wheel generates a reflected echo.

A crack located perpendicularly to the direction of the ultrasonic pulse propagation causes the signal to be reflected. The echo signal, reflected from the defect, and the so-called bottom signals that run around a full circle, are recorded by the transceiver head. In this case, the useful signal is amplified, passes through an electronic filter, and then enters the micro-processor of the module [31-32]. Here it is assessed according to various criteria, and the ratio of the amplitudes of the signals reflected from the defect and the bottom signals serves as a measure for assessing the depth of the crack in the metal layer adjacent to the wheel tread (Figures 4 and 5).

To ensure the high reliability of the presented method, wheel parameters are measured at four points on the circumference of each wheel. To check the measurement accuracy of the automated measuring system, they are compared to manual measurements using special templates. Errors were determined and possible deviations were investigated.

3 Findings and discussion

Based on the assigned tasks, the structure of the automated measuring complex was determined. Measuring sensors consist of 16 units installed evenly at the ¼ distance of the wheel circumference on both sides of a rail. The operating principle of the sensors is laser triangulation. The functional diagram of the automated measuring complex is shown in Figure 6.

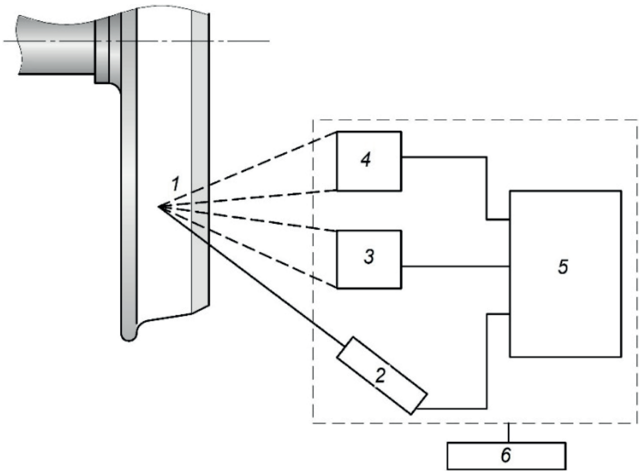

Figure 6 *A functional diagram of an automated measuring complex with feedback on radiation intensity: 1 - wheel, 2 - laser, 3 - photodetector, 4 - measuring cell, 5 - computing module, 6 - controller*

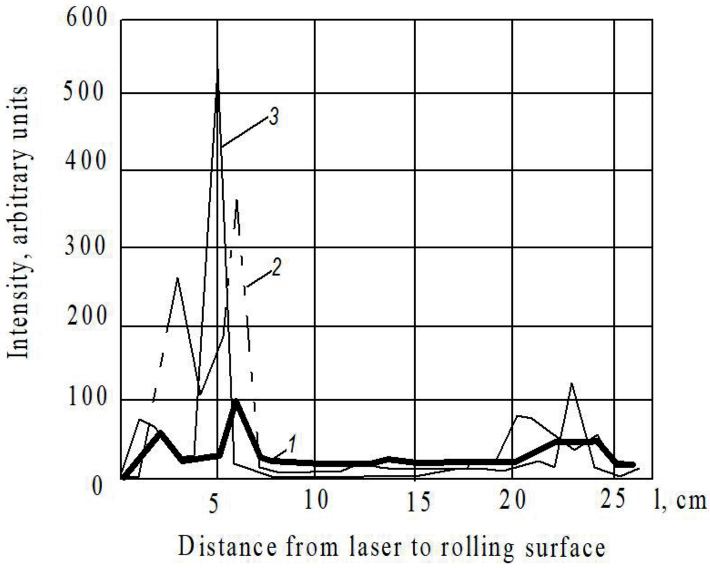

Figure 7 *Dependence of the reflected signal intensity on the position of the laser beam on the rolling surface: 1 - laser beam with a diameter of 0.7 mm; 2 - laser beam with a diameter of 3.5 mm; 3 - laser beam with a diameter of 5 mm*

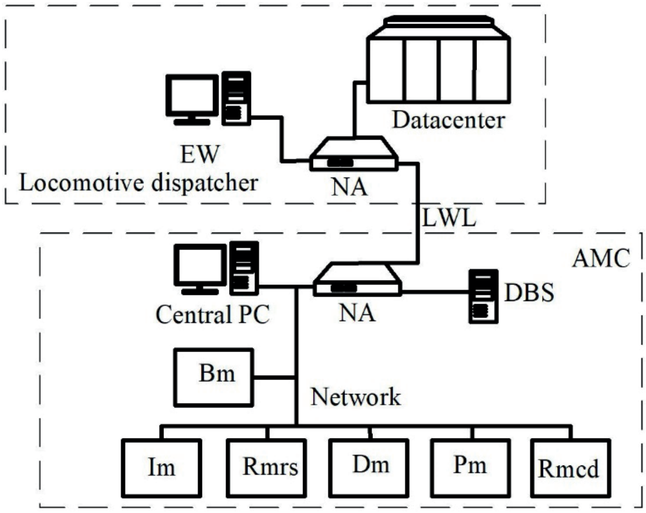

Figure 8 *Networking of measuring and testing modules, base module and operator workstations: EW - external workplace; NA - network device; LWL - fiber optic cable; Central PC - central PC; DBS - Database server; AMC - Automated measuring complex; Bm - basic module; Im - identification module; Rmrs - module for detecting non-roundness and sliders; Dm - wheel diameter measurement module; Pm - profile measurement module; Rmcd - crack detection module*

As the wheel moves, it crosses a beam of laser radiation, and the wheel tire is scanned. The image of the radiation spot on the rolling surface is projected through the lens onto a matrix of linear photosensors.

The position of the spot on the matrix corresponds to the distance from the sensor to a certain point on the rolling surface.

Due to the large inertia of the train, the movement of the wheel during measurement can be considered uniform. The running speed is determined using an inductive axle number sensor. Based on the known values of the distance from the wheel tread to the sensor and the train running speed, the controller calculates the profile and other parameters of the wheel.

The optimal diameter of the probing laser beam for the average wheel tread surface roughness was experimentally selected. The results of measurements performed at different laser beam diameters are shown in Figure 7. Analysis shows that the maximum dynamic range and maximum intensity burst occur with focused laser beam radiation. Increasing the beam diameter from 3 mm to 4 mm does not lead to a decrease in dynamic range. Therefore, the optimal beam diameter value can be considered in the range from 3 mm to 4 mm.

The introduction of a second feedback channel made it possible to increase the accuracy and speed of measurements, as well as to expand the range of applicability of sensors under external illumination conditions.

The automated measuring system is designed for installation directly on the railway track in the area of the entrance to the technical inspection point (TIP). This arrangement of the complex makes it possible to check the wheels of all the passing trains without significantly reducing the speed of movement. In this case, the entire measurement cycle, together with the delivery of information to the operator's console of the TIP, occurs in real time. All measurements of train's wheelsets with the length of 400 m, which moves at a speed of about 10 km/h are performed within 3 minutes. All the measurement results, which provide complete information about the condition of each wheel and wheel pairs, are stored in the digital media.

All elements of the automated measuring complex are combined into a network (Figure 8). The measurement results make it possible to identify wheelsets for wheel turning or replacement of wheelsets. Having the data on the condition of the profile of each wheel, the mode of turning it on a wheel lathe can be preset.

A special software package is used to visualize and analyze the obtained data. It consists of individual software modules that can also be used independently of each other. The main mandatory data showing the train configuration, maximum dimensions and types of measurements are contained in the database. To obtain the necessary information, the computer connects the system database via a network. All the measurement results stored in the database can be quickly accessed using this software package.

Reducing the railway transport maintenance costs (percentage or quantity) depends on the specific car fleet, the availability of equipment for maintenance and repair and many other factors. The main costs of servicing the railway transport are associated with a reduction in labour costs, downtime of rail vehicles and other factors. Specific figures for costs reduction may vary depending on operating conditions and several other factors. The idea of the presented method is to show that the use of an automated measuring system can reduce the servicing railway transport costs by several percent.

4 Conclusions

Regular registration of critical vehicle parameters with their subsequent assessment and analysis is the basis for organizing the reliable and cost-effective condition-based maintenance. Similar technologies are already widely used in air transport. Under operating conditions of rail rolling stock, regular parameters monitoring of wheel pairs, reduces the costs of preventive maintenance work without compromising traffic safety. Of course, the potential for savings in operating costs with increased the traffic safety can only be achieved with regular monitoring of the bogie parameters.

When using the proposed automated measuring system, a short- or long-term prediction of the behavior of any monitored parameters can be performed, which are, e.g. changes in the flange height of a certain wheelset within two weeks. The prediction makes it possible to determine the remaining service life of each wheel pair and plan measures for its repair.

Acknowledgment

This research was supported by the project VEGA 1/0305/23: The research of dynamic properties of mechanical systems of railway vehicles with flexible structural components when running on a track and by the project KEGA No. 031ZU-4/2023: Development of key competencies of the graduate of the study program Vehicles and Engines.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] ROSIC, S., STAMENKOVIC, D., BANIC, M., SIMONOVIC, M., RISTIC-DURRANT, D., ULIANOV, C. Analysis of the safety level of obstacle detection in autonomous railway vehicles. *Acta Polytechnica Hungarica* [online]. 2022, **19**(3), p. 187-205. ISSN 1785-8860, eISSN 2064-2687. Available from: https://doi.org/10.12700/APH.19.3.2022.3.15

[2] KAGRAMANIAN, A., AULIN, D., TRUBCHANINOVA, K., CABAN, J., VORONIN, A., BASOV, A. Perspectives of multifunctional integrated suburban-urban rail transport development. *Scientific Journal of Silesian University of Technology. Series Transport* [online]. 2023, **120**, p. 105-115. ISSN 0209-3324, eISSN 2450-1549. Available from: https://doi.org/10.20858/sjsutst.2023.120.7

[3] LOVSKA, A., FOMIN, O., PISTEK, V., KUCERA, P. Dynamic load and strength determination of carrying structure of wagons transported by ferries. *Journal of Marine Science and Engineering* [online]. 2020, **8**(11), p. 1-14. eISSN 2077-1312. Available from: https://doi.org/10.3390/jmse8110902

[4] FOMIN, O., LOVSKA, A., MASILYEV, V., TSYMBALIUK, A., BURLUTSKI, O. Determining strength indicators for the bearing structure of a covered wagon's body made from round pipes when transported by a railroad ferry. *Eastern-European Journal of Enterprise Technologies* [online]. 2019, **1**(1-97), p. 33-40. ISSN 1729-3774, eISSN 1729-4061. Available from: https://doi.org/10.15587/1729-4061.2019.154282

[5] LYOVIN, B. Integrated monitoring of transport infrastructure. *Science and Technology of Railways*. 2017, **1**, p. 14-21, ISSN 2587-5752.

[6] MORAIS, P., MORAIS, J., SANTOS, C., PAIXAO, A., FORTUNATO, E., ASSEICEIRO, F., ALVARENGA, P., GOMES, L. Continuous monitoring and evaluation of railway tracks: proof of concept. *Procedia Structural Integrity* [online]. 2019, **17**, p. 419-426. eISSN 2452-3216. Available from: https://doi.org/10.1016/j.prostr.2019.08.055

[7] KLIUIEV, S., MEDVEDIEV, I., KHALIPOVA, N. Study of railway traffic safety based on the railway track condition monitoring system. *IOP Conference Series: Materials Science and Engineering* [online]. 2020, **985**, 012012. ISSN 1757-899X. Available from: https://doi.org/10.1088/1757-899X/985/1/012012

[8] KLIUIEV, S. O. Ensuring the safety of railway transport in conditions of digitalization (in Ukrainian). *Bulletin of the SNU named after V. Dalya*. 2020, **5**(261), p. 14-18, ISSN 1998-7927.

[9] PAPAELIAS, M., AMINI, A., HUANG, Z., VALLELY, P., DIAS, D. C., KERKYRAS, S. Online condition monitoring of rolling stock wheels and axle bearings. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* [online], 2014, **230**(3), p. 709-723. ISSN 0954-4097, eISSN 2041-3017. Available from: https://doi.org/10.1177/0954409714559758

[10] HAUSER, V., NOZHENKO, O., KRAVCHENKO, K., LOULOVA, M., GERLICI, J., LACK, T. Impact of wheelset steering and wheel profile geometry to the vehicle behavior when passing curved track. *Manufacturing Technology* [online]. 2017, **17**(3), p. 306-312. ISSN 1213-2489, eISSN 2787-9402. Available from: https://doi.org/10.21062/ujep/x.2017/a/1213-2489/MT/17/3/306

[11] GERLICI, J., LACK, T., HARUSINEC, J. Development of test stand prototype for rail vehicles brake components testing. *Communications - Scientific Letters of the University of Zilina* [online]. 2014, **16**(3a), p. 27-32. ISSN 1335-4205, eISSN 2585-7878. Available from: https://doi.org/10.26552/com.C.2014.3A.27-32

[12] KARDAS-CINAL, E. Statistical analysis of dynamical quantities related to running safety and ride comfort of a railway vehicle. *Scientific Journal of Silesian University of Technology. Series Transport* [online]. 2020, **106**, p. 63-72. ISSN 0209-3324, eISSN 2450-1549. Available from: https://doi.org/10.20858/sjsutst.2020.106.5

[13] TURABIMANA, P., NKUNDINEZA, C. Development of an on-board measurement system for railway vehicle wheel flange wear. *Sensors* [online]. 2020, **20**(1), 303. eISSN 1424-8220. Available from: https://doi.org/10.3390/s20010303

[14] ASKEROV, H., VAKULENKO, I., GRISCHENKO, N. Insights into factors of damage of surface rolling of railway wheels during operation. *Scientific Journal of Silesian University of Technology. Series Transport* [online]. 2019, 105, p. 27-33. ISSN 0209-3324, eISSN 2450-1549. Available from: https://doi.org/10.20858/sjsutst.2019.105.3

[15] ENTEZAMI, M., ROBERTS, C., WESTON, P., STEWART, E., AMINI, A., PAPAELIAS, M. Perspectives on railway axle bearing condition monitoring. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* [online]. 2020, **234**(1), p. 17-31. ISSN 0954-4097, eISSN 2041-3017. Available from: https://doi.org/10.1177/0954409719831822

[16] Transportation Research Board. Rail safety IDEAS programme annual report. Washington, DC: The National Academy of Science, 2018.

[17] DUTTA, S., HARRISON, T. J., SARMIENTO-CARNEVALI, M. L., WARD, C. P., DIXON, R. Modelling and controller design for self-adjusting railway track switch system. In: 7th Transport Research Arena TRA: proceedings [online]. 2018. Available from: https://hdl.handle.net/2134/32959

[18] GIANG, K. L. E. Enhancing traffic safety: a comprehensive approach through real-time data and intelligent transportation systems. *Scientific Journal of Silesian University of Technology. Series Transport* [online]. 2024, **122**, p. 129-149. ISSN 0209-3324, eISSN 2450-1549.Available from: https://doi.org/10.20858/sjsutst.2024.122.8

[19] MACIOSZEK, E. Analysis of the rail cargo transport volume in Poland in 2010-2021. *Scientific Journal of Silesian University of Technology. Series Transport* [online]. 2023, **119**, p. 125-140. ISSN 0209-3324, eISSN 2450-1549. Available from: https://doi.org/10.20858/sjsutst.2023.119.7

[20] LOVSKAYA, A. Assessment of dynamic efforts to bodies of wagons at transportation with railway ferries. *Eastern-European Journal of Enterprise Technologies* [online]. 2014, **3**(4), p. 36-41. ISSN 1729-3774, eISSN 1729-4061. Available from: https://doi.org/10.15587/1729-4061.2014.24997

[21] AMINI, A., ENTEZAMI, M., PAPAELIAS, M. Onboard detection of railway axle bearing defects using envelope analysis of high frequency acoustic emission signals. *Case Studies in Nondestructive Testing and Evaluation* [online]. 2016, **6**(Part A), p. 8-16. ISSN 2214-6571. Available from: https://doi.org/10.1016/j.csndt.2016.06.002

[22] LUBNA, M., MEHDI, G., ZIED, B. Smart gas sensors: materials, technologies, practical applications, and use of machine learning - a review. *Journal of Applied and Computational Mechanics* [online]. 2023, **9**(3), p. 775-803. eISSN 2383-4536. Available from: https://doi.org/10.22055/JACM.2023.41985.3851

[23] KUMAR, S., GOYAL, D., DHAMI, S. S. Statistical and frequency analysis of acoustic signals for condition monitoring of ball bearing. *Materials Today: Proceedings* [online]. 2018, **5**(2), p. 5186-5194. eISSN 2214-7853. Available from: https://doi.org/10.1016/j.matpr.2017.12.100

[24] YANG, T., DU, C., ZHOU, S. Study on reverberation suppression method combined with prewhitening and wavelet transform. *Acoustic Technique* [online]. 2021, **40**, p. 110-116, ISSN 1819-2408.

[25] SUN, R.-B., YANG, Z.-B., ZHAI, Z., CHEN, X.-F. Sparse representation based on parametric impulsive dictionary design for bearing fault diagnosis. *Mechanical Systems and Signal Processing* [online]. 2019, **122**, p. 737-753. eISSN 1096-1216. Available from: https://doi.org/10.1016/j.ymssp.2018.12.054

[26] CHEN, Y., NING, P., FAN, T. An improved fast spectral kurtosis algorithm in bearing fault diagnosis for a motor drive system. In: IEEE 6th International Electrical and Energy Conference CIEEC: proceedings [online]. IEEE. 2023. eISBN 979-8-3503-4667-1. Available from: https://doi.org/10.1109/CIEEC58067.2023.10166214

[27] FISCHER, S., SZURKE, S. K. Detection process on energy loss in electric railway vehicles. *Facta Universitatis, Series: Mechanical Engineering* [online]. 2023, **21**(1), p. 81-99. ISSN 0354-2025, eISSN 2335-0164. Available from: https://doi.org/10.22190/FUME221104046F

[28] SEMENOV, S., MIKHAILOV, E., DIZO, J., BLATNICKY, M. The research of running resistance of a railway wagon with various wheel designs. In: Transportation Science and Technology Lecture Notes in Intelligent Transportation and Infrastructure TRANSBALTICA XII: proceedings [online]. 2022. ISBN 978-3-030-94776-7, eISSN 2523-3459, p. 110-119. Available from: https://doi.org/10.1007/978-3-030-94774-3_11

[29] SEMENOV, S., MIKHAILOV, E., KLIUIEV, S., DIZO, J., BLATNICKY, M., ISHCHUK, V. Improving the energy efficiency of a tram's running gear. *Acta Polytechnica* [online]. 2023, **63**(3), p. 216-226. ISSN 1210–2709, eISSN 1805–2363. Available from: https://doi.org/10.14311/AP.2023.63.0216

[30] VATULIA, G., LOVSKA, A., PAVLIUCHENKOV, M., NERUBATSKYI, V., OKOROKOV, A., HORDIIENKO, D., VERNIGORA, R., ZHURAVEL, I. Determining patterns of vertical load on the prototype of a removable module for long-size cargoes. *Eastern-European Journal of Enterprise Technologies* [online]. 2022, **6**(7), p. 21-29. ISSN 1729-3774, eISSN 1729-4061. Available from: https://doi.org/10.15587/1729-4061.2022.266855

[31] DAI, W., MO, Z., LUO, CH., JIANG, J., MIAO, Q. Bearing fault diagnosis based on reinforcement learning and kurtosis. In: 2019 Prognostics and System Health Management Conference PHM-Qingdao: proceedings [online]. IEEE. 2019. eISBN 978-1-7281-0861-2. Available from: https://doi.org/10.1109/PHM-Qingdao46334.2019.8942977

[32] OSORIO SANTANDER, E. J., NETO, S., VAZ, L.V., MONTEIRO, U. A. Using spectral kurtosis for selection of the frequency bandwidth containing the fault signature in rolling bearings. *Marine Systems and Ocean Technology* [online]. 2020, **15**, p. 243-252. ISSN 1679-396X, eISSN 2199-4749. Available from: https://doi.org/10.1007/s40868-020-00084-2