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Faculty of Transport and Aviation Engineering

Department of Transport Systems, Traffic Engineering and Logistics

Method of Assessing the Condition of Wheels of Wheelsets of Railcar During Railroad Drive

A dissertation submitted to the Joint Doctoral School of Silesian University of Technology in the fulfilment of the Doctor of Philosophy in Civil Engineering, Geodesy and Transport

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Extended Summary

Effective maintenance of railway vehicles requires ongoing diagnostics of the technical condition of vehicle components, in particular the wheel systems. The condition of the railcar wheels determines the efficiency and safety of vehicle traffic. A well-known methodology for diagnosing the condition of wheels is based on the analysis of signals from sensors located on wheel hubs, on rails or near tracks. The vibrations of the wheels or rails, the sounds generated by the wheels, or the relative displacements of the wheelset components are measured. The developed measurement solutions include speed sensors, microphones or strain gauges that require careful handling. The analysis of the signal is performed in the time, frequency and time-frequency domains.

The task of verifying the methodology using the measurement of vibration signal parameters were undertaken. The assessment of the condition of tram wheels was chosen as the field of research. Maintenance of tram vehicles is an important issue for the transport system of the Silesian Agglomeration. Tram transport is a significant element of the system and is part of the policy of reducing the carbon footprint implemented by the authorities of the Region.

The specifics of tram vehicles are: much lower weight and low speeds of movement in comparison to rolling stock this leads to the reduction of required ranges of signal parameter measurements. Preliminary tests were carried out and spectra of vibration signals, important for the diagnosis of wheel condition, in the frequency range of 50 – 500 Hz were obtained. The maximum values of vibration accelerations did not exceed 200 [m/s^2]. Such a range of vibration parameters can be measured with the use of available acceleration sensors made in the form of electromechanical microcircuits - MEMS.

The research question is formulated: How can MEMS acceleration sensors be used to assess the condition of wheels of wheelsets of railcars during a railroad drive? The analysis of sensor signals in the time-frequency domain is proposed to take into account

the influence of vehicle movement during tests. The following research hypotheses are formulated: The analysis of the vibration image in the frequency range of 0 – 500 Hz of the rails on which the vehicle moves enables the assessment of the condition of the wheels. The vibration energy of the rails in characteristic frequency bands indicates the condition of the wheels.

Limitations for the implementation of measurements resulting from the practice of traffic dispatchers in the depot are adopted. I practice a vehicle is observed passing at a low speed and when the level of noise generated while driving causes "anxiety" for the dispatcher he prevents the vehicle from leaving the depot. Movement speed is limited to a few km/h. The measuring sensor is placed on the manoeuvring track in the depot and does not affect the movement of the vehicle.

A literature query allows us to identify several approaches to the issue of wheel condition assessment. A distinction can be made between evaluation methods using onboard sensors mounted on bogie components or vehicle structures. Onboard solutions can provide real-time information and indicate the need for maintenance, but this is associated with the high costs of installing sensors and maintaining them in working order. The authors of the studies prove the high usefulness of onboard sensors for the assessment of the condition of the wheels and for the implementation of maintenance tasks in accordance with the assumptions of the CBM strategy (maintenance based on the assessment of technical condition).

The use of sensors outside the vehicle is the domain of methods based on measurements of the impact of the vehicle's wheels on the rails or on measurements of the generated noise in the track environment. Measuring the degree of rail deformation or recording the parameters of vibrations caused by the wheels allows for mapping the course of the impact and reveals anomalies when the vehicle has damaged wheels. The authors of the attempts presented in the literature to analyze signals from sensors for the assessment of the condition of wheels define significant limitations for obtaining correct evaluation results. First of all, the speed of travel, the condition of the track, the type and technical condition of the bogie are mentioned as factors determining the ability to correctly describe the technical condition of the wheels.

The developed methods based on the assessment of vehicle passing noise are sensitive to ambient noise. Published studies recommend subjecting the acoustic signals from the sensors to filtration in the frequency domain to eliminate interference. The authors draw attention to the necessity of careful assessment of sources in the environment in order to

identify the frequency ranges of masking the passage sounds.

The solutions of measurement systems presented in the literature provide data streams that are subject to analysis in the time, frequency or time-frequency domain. The authors propose the use of well-known methods of analysis based primarily on Fourier and wavelet transformations. Discussions of the properties of the selected methods do not give a clear indication of the best method of analysis. An important premise for the choice of the analysis method, emphasized by the authors of the papers, is the non-stationary nature of the sensor data. Effective analysis requires the linking of time and frequency characteristics to obtain a description that will be useful for determining waveform anomalies and linking them to the technical condition of the wheels. Wavelet transformations are distinguished due to their ability to describe waveforms at different time scales and at different frequency resolutions.

When reviewing the properties of wavelet transformations, attention was paid to the MODWPT transform based on decomposition with the use of wavelet packets. Packet analysis based on a binary decomposition tree provides a description in higher resolution both in time and in the frequency domain, hence the ability to describe the measurement data in more detail is obtained. The selection of the base wave and the level of decomposition is the subject of optimisation in order to obtain an effective tool for assessing the condition of the wheels. There are no papers in the literature undertaking the task of optimising MODWPT parameters for the assessment of the technical condition of wheels.

A method was developed to assess the condition of the wheels using data from an acceleration sensor that records rail vibrations during the passage of the vehicle. The MODWPT transform and vibration energy in characteristic frequency intervals were chosen as the basis for the processing. As a criterion for optimisation, the relative difference between the vibration energy of "good" and damaged wheels in a given frequency range was proposed. Optimisation of transform parameters was carried out, the type of base wavelet, the required level of decomposition and characteristic frequency ranges that are important for the assessment of the condition of the wheels were determined. The optimisation task was carried out using data from initial measurements of vibrations during tram journeys in the depot.

The method was validated during test runs of trams on the depot's shunting tracks. A prototype of an acceleration sensor based on a 3-axis accelerometer made in MEMS technology was used. Accelerations of vibrations of rails on which the vehicle was moving

at a frequency of 1 kHz were recorded. The vehicle was fitted with wheels damaged to varying degrees. The energy of the recorded signals was calculated using the MODWPT transform coefficients with the Coiflet3 base wave at the 8^{th} decomposition level in the frequency range of 420 – 422 Hz.

The results of the validation confirm that the possibility of using sensors in MEMS technology to assess the condition and, above all, to signal passages with damaged wheels. The use of the MODWPT transform effectively allows the description of vibration anomalies and thus indicates wheel conditions. The established parameters of the MODWPT transform may need to be corrected when the drives are made on tracks in poor technical condition and when the travel speeds exceed a few km/h. The developed method has been successfully used to detect wheel fault conditions while driving.

Keywords: wheel fault condition assessment; MEMS-based sensor; MODWPT; wavelet coefficient; weighted difference; decomposition level; vibration energy; frequency band.