TECHNICAL STATE ASSESSMENT OF A LIGHT RAIL TRACK WEAR BASED ON TRAMWAY DYNAMIC MODEL

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Summary

This article presents an approach of a technical state monitoring method in aimed to the railway track wear diagnostic and its influence on the rail vehicle dynamics. The method is based on the vehicle dynamic response measurements in order to determinate principle excitations and their influence on the vehicle ride safety. Measurements are performed with accelerometers and inclinometers mounted on the measuring bogie. In this paper, authors present assumptions, methodology, the most important results and conclusions of performed numerical and experimental research.

Keywords: track wear, dynamic response, tramway.

OCENA STANU TECHNICZNEGO ZUŻYCIA TORU TRAMWAJOWEGO
W OPARCIU O MODEL DYNAMICZNY LEKKIEGO POJAZDU SZYNOWEGO

Streszczenie

W artykule przedstawiono propozycję metody monitorowania stanu technicznego toru tramwajowego w aspekcie diagnostycznym oraz wpływ jego zużycia na dynamikę pojazdu szynowego. Prezentowana metoda bazuje na pomiarze odpowiedzi dynamicznej pojazdu w celu określenia zasadniczych wymuszeń oraz ich wpływu na bezpieczeństwo jazdy pojazdu szynowego. W pomiarach wykorzystano akcelerometry i inklinometry zainstalowane na wózku pomiarowym. W referacie autorzy zaprezentowali założenia, metodykę, najważniejsze wyniki oraz podsumowanie przeprowadzonych badań numerycznych i eksperymentalnych.

Słowa kluczowe: zużycie toru, odpowiedź dynamiczna, tramwaj.

1. INTRODUCTION

The increasing use of modern light rail systems requires increasing safety standards and, consequently, accurate railway tracks. In many polish cities, light rail track wear is one of the most important factor, deciding on the light rail vehicle running safety. That's why track wear should be frequently measured in order to define proper speed limits on each track section. Nevertheless it appears that there are no widely accepted criteria of light rail vehicle running safety on a worn track profile. Consequently the light rail transit industry frequently relies on practices developed primarily for heavy rail transit and railroad freight operations that are not necessarily well suited for light rail systems [5].

For surveying tasks in the context of rail construction, many different systems exist [e.g. 1, 4, 6]. Apart from still used conventional static methods, kinematic measuring systems become more important. The most popular class of a rail track measurement devices are the one-man-track-surveying trolleys, operating with speeds of up to one to three kilometers per hour. These are commonly used by the LRV operators in many cities all over the world. Unfortunately, these systems, that are very light (3-50 kg) could not be used to study the behavior of the rails under dynamic stress for different velocities.

For these reasons, Division of Rail Vehicles (Poznan University of Technology) developed a light rail track surveying platform in co-operation with Poznan Trams Operator – MPK Poznan (PL).

2. METHODOLOGY

In polish cities, the main wheel profile for light rail vehicles is a PST profile, presented in figure 1. There are two main rail profiles used for the light rail track. The UIC-60 rail profile is commonly used in straight track sections, and the Ri59N girder groove rail is used in curves.

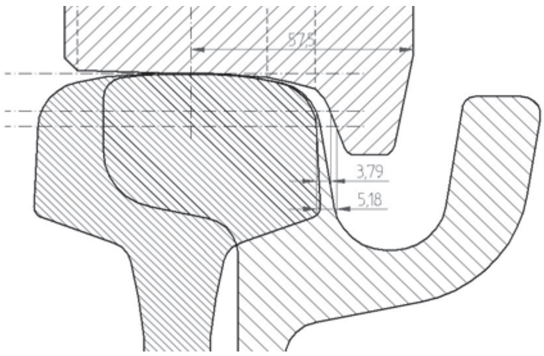

Fig. 1. Wheel/rail interface for LRV [3]

The combinations of wheel and rail profiles shown in figure 1 illustrate the various interface conditions that could be generated between the wheels and rails. The mathematical analysis has been conducted in order to understand the mechanisms involved in track and light rail by the vehicle interaction and their impact on vehicle safety. All geometric parameters in straight track and sharp curve were calculated from numerical CAD model analysis, using a Solid Edge software [3].

The basic assumptions of the presented method are:

1. The vehicle bogie is new (or after being refurbished) in order to insure constant and defined damping and stiffness parameters. Spring rate is the force per travel distance for the coil or chevron primary springs. This relationship is non-linear for long travel distances. The equivalent vertical, longitudinal, and lateral spring rates will be different.
2. The wheel profile is new, or without significant use, in order to insure stable vehicle ride on track. The wheel profile is one of the most critical vehicle parameters to consider in track design and the primary interface between the vehicle and the track structure.
3. The main modal parameters are identified. Trucks and car bodies have different natural frequencies that should also be considered. Also, car weight changes (due to different passenger load) affects the car body's natural frequency.

These assumptions guarantee, that all recorded vibrations, are due to the track wear, and not to the bogies structure faults.

3. NUMERICAL APPROACH

In order to better understand track wear influence on the vehicle dynamic response, a numerical model of the light rail vehicle was built in a simulation software Universal Mechanism (a Multibody System Dynamics package). Typical models used for rail dynamics consist of only 7 bodies. Such a model is not sufficient for a LRV, which commonly has an elastic bogie frame, that must be modeled in a different way (this elastic bogie frame ensure better ride stability on a worn track). That's why the created physical model, presented in figure 2, consists of 19 rigid bodies and 53 joint between them.

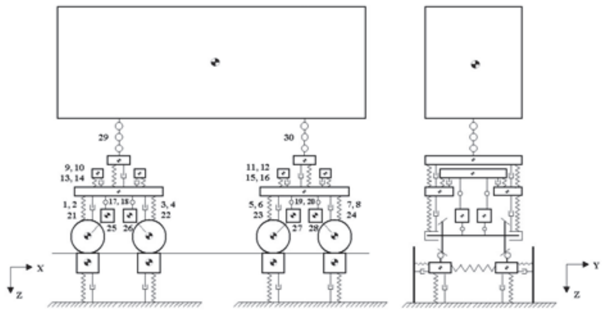

Fig. 2. Physical model of a LRV

The simulation model was created in Universal Mechanism software.

A validation of the main model parameters (natural frequency, stiffness and damping coefficients) took place on the real vehicle, by means of accelerometers and displacement sensors, performed in three stages:

1. Modal analysis of the vehicle bogie; in this research, a modal test was applied on the bogie structure, using an impact hammer, in order to determinate a Frequency Response Function (FRF) for all measuring points.
2. Wedge tests of the vehicle bogie; in this research, a quasi-static ride of a single bogie through different wedges of known geometry was performed. Measuring of wheelsets, bogie frame and motor beams acceleration permit to find a single bogie response on that kind of irregularities
3. Wedge tests of the entire vehicle; in this research, a quasi-static ride of the vehicle through different wedges of known geometry was performed.

After validating the most important model characteristic, many simulations were made, in order to find critical speeds, maximum force and maximum acceleration values under several track wear conditions – in straight track as well as in curved sections.

4. FIELD TESTS AND RESULTS

After validating all bogie parameters, ride tests of entire vehicle in normal operation tram regime were performed in the city of Poznan (PL), in order to find vehicle structure response on different kind of track irregularities. For this analysis, a measuring bogie was designed and built on the base of a standard 105N tram bogie (figure 3). Acquisition and data collection system based on a multianalyzer platform PULSE® made by Brüel & Kjær with portable data acquisition unit type B&K 3650C. That system version was fitted with a 5/1-ch. Input/Output Controller Module Type 7537 and a 12-ch in Dyn-X® technology. Input Module ensures synchronous measuring up to 17 input channels in wide frequency range from DC to

25,6 kHz [7]. Measurement system was equipped with an accelerometer set: type B&K 4504 (3 pieces), 4506, 4383 and 2 inclinometers for detection of a relative wheelsets rotation.

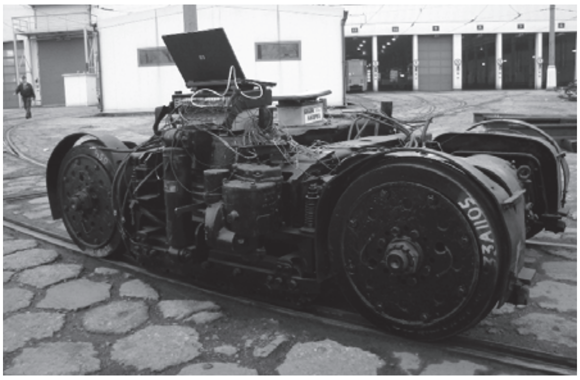

Fig. 3. Measuring test bogie equipped with measurement set

The first stage of this analysis, consists of testing the measuring bogie uncoupled from the carbody on different track irregularities, in order to calibrate all measuring devices, check and verify all the measuring system.

In the second stage, a measuring bogie was mounted under a standard tram and made few measurements on the tramway track in Poznan – measuring vehicle response to different track geometry, under several speed and load conditions. Representation of a tram ride via 30m curve in a vibration signal and inclinometer output is shown on figure 4.

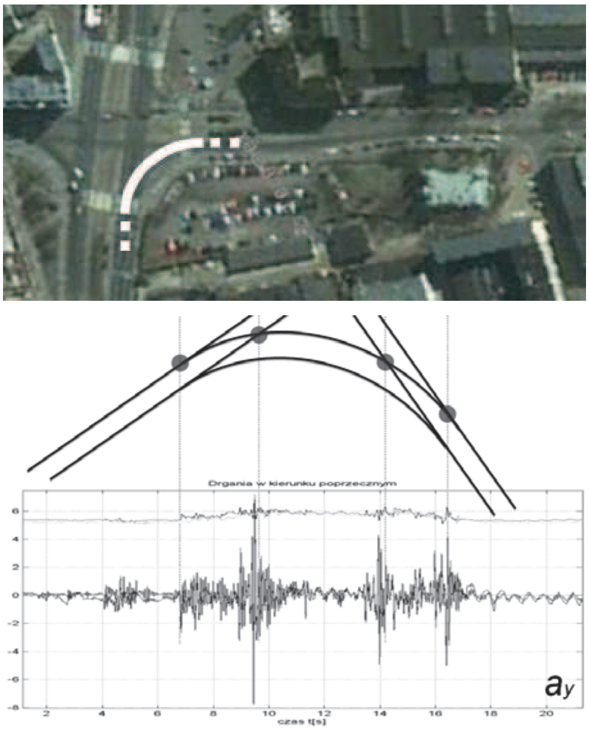

Fig. 4. Acceleration and wheelsets relative revolution signals recorded during a ride via 30m curve

Figures 5 and 6 shows the acceleration values, recorded in two axis (y and z) during a ride through the two kind of straight track section: worn and without significant use. Upper windows present time history of acceleration signal and lower windows include its spectra.

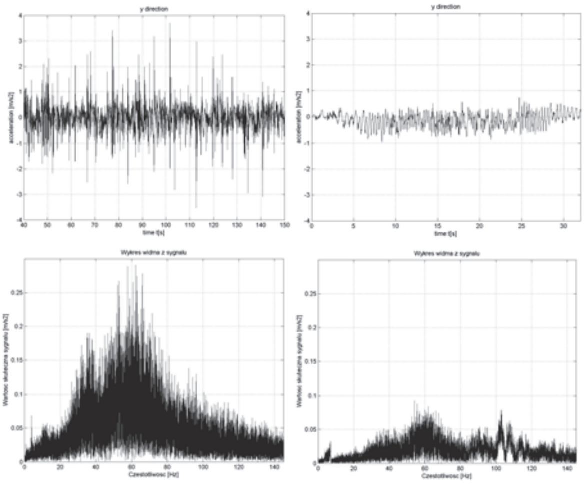

Fig. 5. Time history of acceleration signal and its spectra – *y* direct;
left – worn track
right – new track

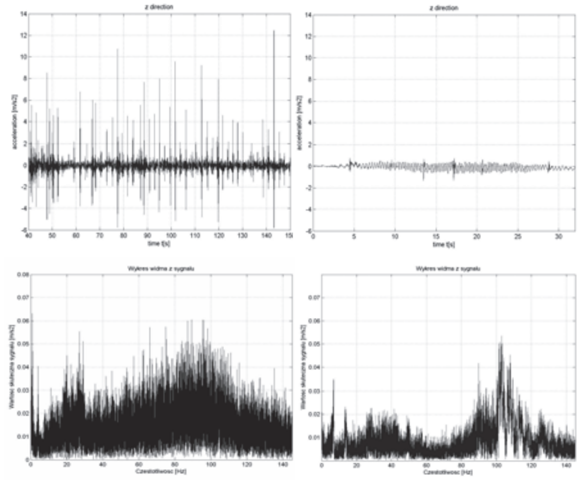

Fig. 6. Time history of acceleration signal and its spectra – *z* direct;
left – worn track
right – new track

Maximum horizontal acceleration values on a wheelset are 3.5 m/s^2 and maximum vertical acceleration values recorded in this curve are 12.5 m/s^2, but they do not cause a derailment of the measuring vehicle, in spite of the fact, that the limit value for a heavy rail vehicle is lower than this value [2]. In lower windows of the figures 5 and 6 are the analysis of a ride through the same track sections, but in frequency domain. In a 20-40 Hz frequency range an interesting signal component can be seen, that is not due to structure resonance (seen between 80-100 Hz in horizontal, and 60-80 Hz in vertical direction), but is related to track irregularities excitation.

5. CONCLUSION

The presented method is an approach of a technical state monitoring method in aimed to the railway track wear diagnostic and its influence on the rail vehicle dynamics. The analysis reveals, that there can be a relation between a track wear degree and an acceleration value of the wheelset. Frequency domain acceleration analysis could be use to determine some new, qualitative track wear global criteria for light rail track, based on RMS values in selected range. Detailed information about local irregularities can be taken from time history of acceleration and relative revolutions wheelsets signals.

The analysis shows also, that a light rail vehicle behavior on a worn track is different then for a heavy rail vehicle. It is due to different construction characteristic and destination of those vehicles, who must ride into sharp curves in city centers. Nevertheless, the derailment risk on the straight track is very low at speeds authorized for LRV (max. 70 km/h). In this situation, the most important and harder criterion in technical state assessment of a light rail track wear should be a human vibration comfort of riding.

This assumption is now verified for different track section.

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