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Analysis of Freight Wagon Wheel Failure Detection in Lithuanian Railways

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Abstract

The authors of this paper analyze the freight wagon wheel rolling surface damage detection process in Lithuanian Railways. The wagons were selected for this study in consideration of the Wheel Impact Load Detector (WILD) database. The results gained by experimental measurements of wheel rolling surface defects were compared with the data recorded by WILD. Distribution of failures of wheel types and dependence of the influence of the wheel-set location in a wagon on the occurrence of different defects of wheels was defined. The authors examined the reliability of WILD read-outs and wheel defect types influence on the dynamic coefficient value. Finally, basic conclusions and recommendations are given.

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Keywords: rolling-stock wheel wear; wheel flat; rolling-stock control siding equipment; reliability of read-outs.

1. Introduction

With a train moving on rails, a phenomenon of wheel-set stroke against the rail head occurs inevitably. This phenomenon is mainly caused due to the wheel rolling surface derailment, i.e. loss of contact (Меланин 2010; Bureika et al. 2013). This occurs as a result of the surface roughness on the wheel and rail. Roughness often is of jumping type: wheel flats, cracks and rail couplings. This type of wheel damage occurs when the wheel locks and slides along the rail because of malfunctioning brakes or because the braking force is too high in relation to the available wheel/rail

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friction (Pieringer et al. 2014). Not so abrupt roughness also occurs, including uneven wheel wear, corrugated rail cracks and roughness due to wheel slippage. They also, at certain speeds, may create conditions for wheel derailment. With the emergence of strokes at the wheel and rail contact, the vertical forces may increase up to 10 and more times, thus causing serious damage of the rolling stock and the track and enhancing risk to the safe train traffic (Сладковский et al. 2008). With increasing vehicle velocity, the dynamic forces caused by these disturbances increase as well (Popp et al. 2010). Therefore, it is necessary to identify the said faults of the rolling stock in due time and as much precisely as possible and to eliminate them. Special methods are necessary for exploring the vertical wheel and rail interaction, since these processes at strokes are becoming of high frequency. Duration of the highest momentary force action in the wheel and rail contact depending on the train motion speed covers several milliseconds or even less. This has been fixed by the Wheel Impact Load Detector (WILD) database.

This paper deals with the process of detection of wheel defects in moving trains and processing of the data obtained.

2. Equipment of rail vehicle wheel detection

During research the Wheel Impact Load Detector (hereinafter – WILD) system was used by the Lithuanian Railways lines to constantly measure the vertical wheel and rail interaction force of the riding rolling stock through the overall wheel perimeter. Measurement results are related to the specific train number, wheel-set number and the train side. Additionally, the train speed, number of axles and train passing time are fixed. The basic component of a WILD system is the track mounted sensor array (see Fig. 1).

Fig. 1. Wheel impact load detector.

There are two basic types of sensors, the original sensors are based on strain gauges and measure force and the new type is based on accelerometers and measures rail motion. The sensors are installed at strategic places along the track to monitor passing trains to investigate specific safety related symptoms.

The installation of WILDs requires no radical modification of the existing track structure. A series of strain gauge load circuits, micro-welded directly to the neutral axis of a rail, creates an instrumented zone for the measurement of vertical forces exerted by each wheel of a passing train. Signal processors, housed in a nearby unit, electronically analyze the data to isolate wheel tread irregularities. If any wheel generates a force that exceeds a tailored alarming threshold, a report identifies that wheel for action. A low-level alarm identifies trains for service at the next available opportunity; and a high-level alarm directs a train to stop as quickly and safely as possible to avoid a potential derailment. These reports are usually distributed in real time to such interested parties as rail traffic control centres and car shops.

Using rail mounted strain gauges as the wheel sensors, it can weigh each wheel of a train as it passes over, and detect skid flats in the wheels. A wheel with flat spots can create impact loads many times higher than the fully-loaded weight of the wagons it carries and cause serious damage to the railroad.

New WILD systems use an array of accelerometers to measure the change in motion. Air bags in wagons are released when an accelerometer senses sudden extreme changes. When the wheel goes over them, they read positive and as the wheel rolls past, they read negative. Any irregularities in the wheel cause the signals to go both positive and negative as the wheel rolls over them.

The array of sensors is mounted on track, together with an Automatic Equipment Identification (AEI) tag reader which determines the wagons ID when a train passes, identify and trace every wheel in the fleet for as long as that wheel is in service. The data gathered for each axle is automatically recorded on a database by the signal processor and the control PC. It is then transmitted to the railway control centre or depot maintenance centre for remote monitoring and diagnosis.

When a wheel generates a force that causes too high an impact such as it reaches a predetermined impact level compared to the historical value (e.g., a freight wagon's wheel exerts a peak the dynamic coefficient 9 (Danger 1) or above, is considered "out of round" and is on the path to failure (see Fig. 2).

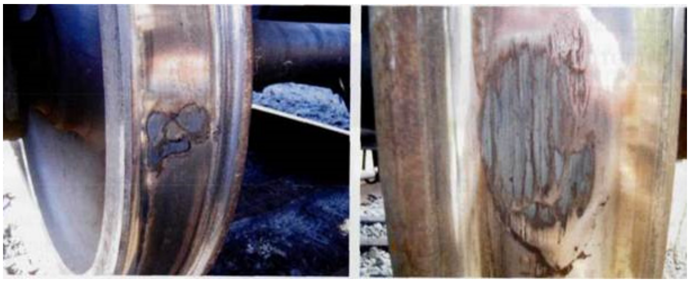

Fig. 2. Inadmissible wheel flat on the wheel rolling surface.

It is the beginning and the end of a measuring strip. The dynamic coefficient (hereinafter the DC), which to be drawn from the following formula, provides information on the status of the wheel, the higher the DC, the higher the degree of wear of the wheel.

The dynamic coefficient is calculated from the following formula:

$$DC = \frac{Q_{\max}}{Q_{stat}}, \tag{1}$$

where $Q_{\max}$ is the highest indicated vertical dynamic force on the wheel; Q_{stat} is the vertical static force on the wheel.

The dynamics are referred to as semi-normalized impact forces as they cancel out the effect the weight has on the impact reading. For example, a wheel carrying bigger weight will have a higher peak load simply because of the greater static force on the wheel. Similarly, a train moving at a higher speed will have a higher peak load just because of the higher dynamic forces on the wheel. Since the DC cancels out the effect the vehicle weight has no impact on a reading, but the speed of the train still affects their readings-out, these are considered only semi-normalized impact values.

This work is aimed at exploring the confirmation of reliability of failures fixed by a WILD system, distribution of failure types, and dependence of emergence of different failure types on the wheel-set location in a wagon.

3. Mathematical models of a wheel flat impact on the rail

Not all wheel and rail contact dynamic models take into account a degree of wheel wear and damage. To estimate the stroke force of a wheel flat on the rail, the following formula may be used:

$$Q_{\max} = v\frac{Z_n}{r}\sqrt{\frac{c \cdot m_{un} \cdot m_r}{m_{un} + m_r}}\,, \tag{2}$$

where v is the train speed, m/s; Z_n is the wheel flat length, m; r is the wheel radius, m; c is the rigidity at the wheel and rail contact, N/m; m_{un} is the unsuspended mass, t; m_r is the rail mass, t.

It is notable that a formula (2) does not estimate the suspended mass, impact of primary and secondary suspension, track roughness, etc. (Myamlin et al. 2015). Mathematical models for a dynamic impact of a wheel flat on the rail are most often formulated using the inverse Laplace transform, which was studied in the works by the Russian scientist Kogan (Коган et al. 1984, 1997, 2003).

These models have been later improved by the scientists from Russia and other countries (Кудюров et al. 2010; Wallentin et al. 2005; Гарипов et al. 2011).

In studying a wheel/rail contact by means of the dynamic modelling program package “Universal Mechanism”, no opportunity exists for assessing the emergence of wheel failures and their impact on the striking forces. The Polish and Russian scientists (Сладковский et al. 2008) proposed a method for solving this problem by modelling the corresponding “simulated” rail irregularity, the diagram thereof is provided in Fig. 4.

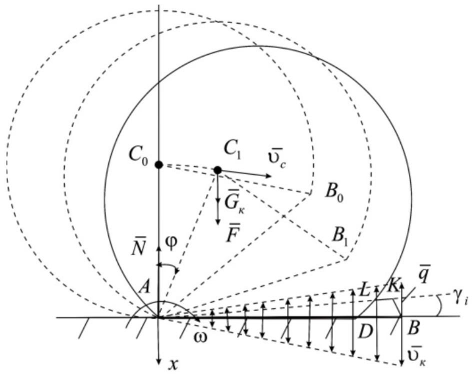

Fig. 3. Wheel flat and rail contact diagram (Гарипов et al. 2011).

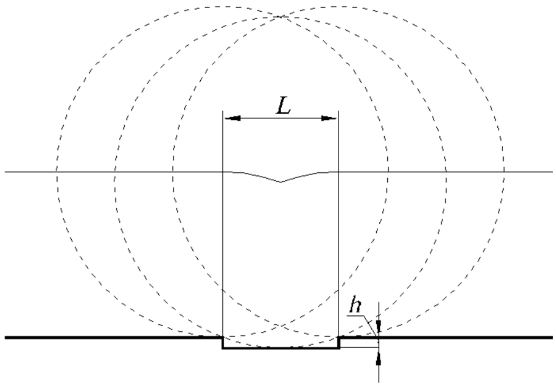

Fig. 4. Rail irregularity simulating the “ideal” wheel flat (Сладковский et al. 2008).

Upon performance of calculations with the given model, the dynamic interaction of wheel flat and rail was established at the varying wagon speed and axle load (Fig. 5).

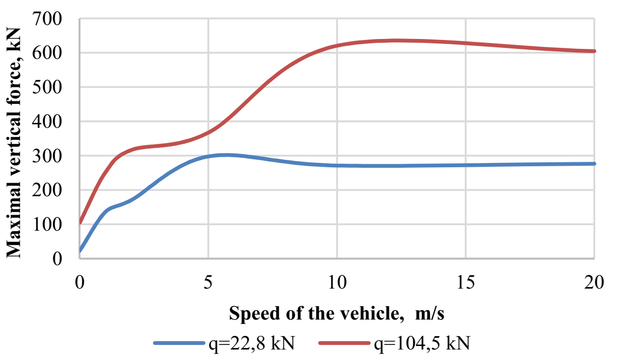

Fig. 5. Vertical force dependence in the wheel/rail contact on the wagon speed and axle load.

Making an analysis of an empty wagon, it is seen that with a speed increase the striking force as compared to the static one may be higher by up to 12 times, i.e. the dynamic coefficient value is 12. The dynamic coefficient of the fully-loaded wagon, as is seen, would be just 5.8. A conclusion can be drawn that the dynamic coefficient of an empty wagon increases more rapidly, since at the same speed the wheel contact with rail is lost for a longer period.

4. Experimental measurements of wheel surface defects

Danger levels and dynamic coefficients fixed in the wagons were analyzed by failure readings as fixed at the WILD post. The authors analyzed failures of those rolling stocks, which, according to the WILD fixed values, were halted for a detailed survey with the purpose of more accurate identification of failures and measurement of their dimensions. Wheel rolling surface failure depths and roughness were identified by their measuring with a railway absolute template (Fig. 6), and crack lengths were measured with a ruler (Fig. 7). Dimensions of measured failures were processed, and their compliance with the permissible parameter values according to the railway technical normatives was assessed.

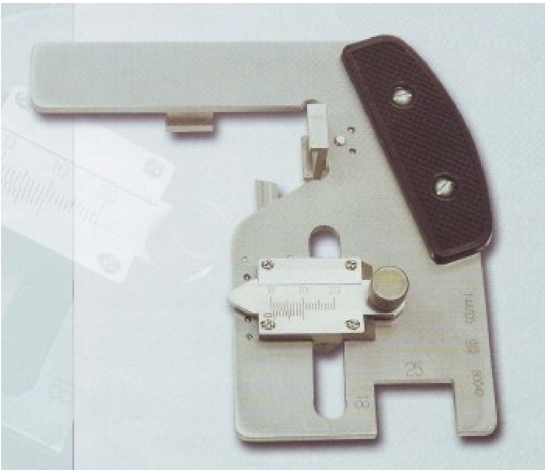

Fig. 6. Railway absolute template.

Fig. 7. Crack length measuring with a ruler.

WILD Danger 0 (due to the wheel rolling surface failure, the train can move to the nearest station, where technical staff must perform an axle-box inspection in more detail and identify the cause of heating) and Danger 1 (due to the wheel rolling surface failure, the train is stopped at a way-station and technical staff is called) levels are examined.

During research it was identified that under WILD Danger 0 and 1 levels 23 wheel rolling surface failures in 66 wagons were fixed. Upon exhaustive inspection of fixed wagon failures of the stopped trains and performance of natural measurements of failures, wheel rolling surface failures were determined in 78 wheel-sets of 66 wagons (in 9 wagons failures were fixed in 2 wheel-sets and in one wagon even in three wheel-sets). During exploration it was identified that of 66 wagons no failures were observed only in one wagon. Accordingly, it may be stated that reliability of WILD readings is more than 99%.

According to WILD level dangers, the number of the wagon wheel-sets with failures is given in Fig. 8.

A WILD system fixed Danger 0 in 55 wheel-sets of 51 wagons and Danger 1 in 23 wheel-sets of 21 wagons.

Upon performance of field measurements of wheel-set rolling surface failures and their compliance with the limit parameter values permissible in operation (wheel flat depth up to 10 mm; uneven wear up to 2.5 mm), it was determined that not all WILD fixed failures are of limit values, and therefore no necessity exists for train stopping for detailed inspection. Confirmation and non-confirmation of data readings relevant to WILD Danger 0 and 1 levels is provided in Fig. 9.

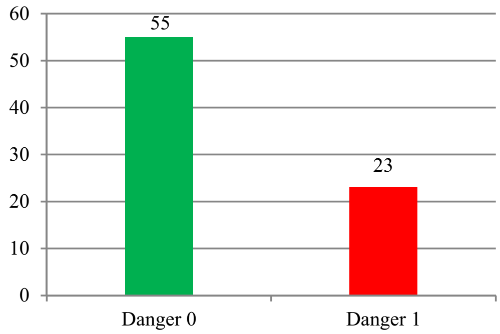

Fig. 8. Number of wheel-set failures according to WILD danger levels.

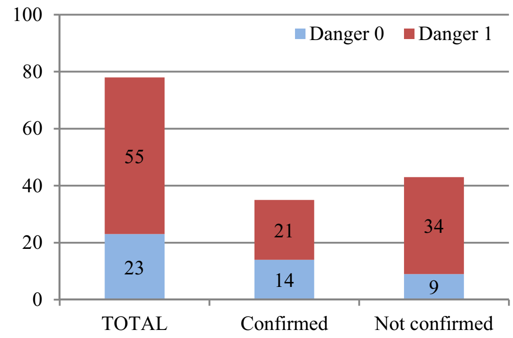

Fig. 9. WILD Danger 0 and Danger 1 readings confirmation data.

Fig. 9 shows that of 55 wheel rolling surface failures fixed under WILD Danger 0 level, only 21 failures were confirmed (confirmation reliability 38%), and of 23 fixed failures of Danger 1 level only 14 were confirmed (confirmation reliability 61%). The total reliability of confirmation of WILD fixed failures accounts only for 45%. Upon performance of analysis it was determined that of 23 halted trains 5 trains could be not halted (failures fixed here were of permissible dimensions).

After field measurements of failures performed, 83 wheel rolling surface failures were identified. Distribution of the identified wheel failure types is depicted in Fig. 10.

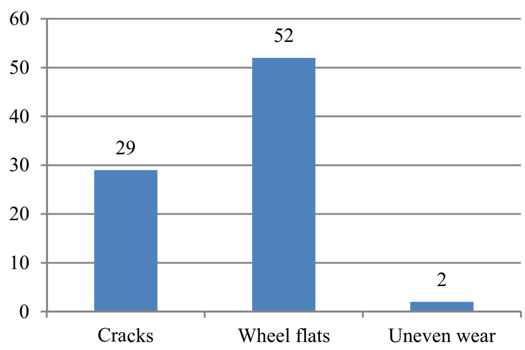

Fig. 10. Distribution of wheel rolling surface failures.

Fig. 10 shows that almost 64% of all failures consist of wheel flats and 35% of cracks.

Upon performance of field measurements it was determined that of 23 cracks even 17 were within the permissible limits of dimensions (length up to 50 mm or depth up to 10 mm), of 52 wheel flats even 25 were within the permissible limits of dimensions (depth up to 1 mm), and both uneven wears were within the permissible limits of dimensions (depth up to 2.5 mm).

Distribution of wheel failures does not depend on the wheel-set location in a wagon since their distribution in wheel-sets (between all 4 wheel-sets) is equal. This phenomenon is explained by the fact that wheel failures arise due to the wagon distribution process when stopping the wagons rolling down from the distributing hill with hand wheel brakes (one wheel has run over the wheel brake shoe, another is sliding on the rail, and a failure is formed at the site of the contact).

During research, it was identified that at the presence of wheel rolling surface failures the dimensions whereof do not comply with the technical requirements, the WILD fixed DC in the laden wagon is lower than that in the event of failures in an empty wagon (see Figs 11 and 12).

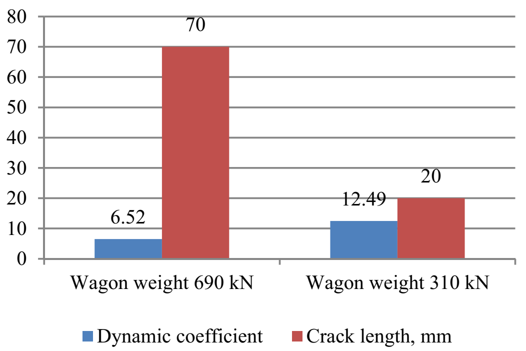

Fig. 11. Dependence of WILD fixed values of dynamic coefficients and crack dimensions on the wagon weight.

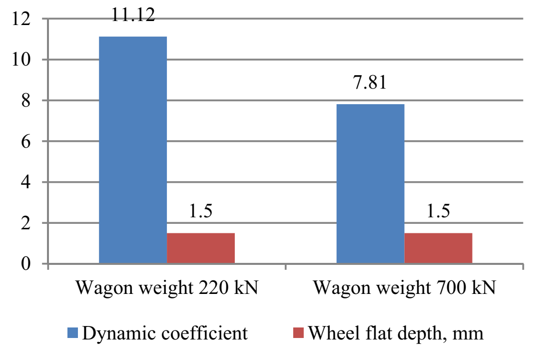

Fig. 12. Dependence of WILD fixed values of dynamic coefficients and failure dimensions on the wagon mass.

During research, wheel flat and crack correlation coefficients were calculated, i. e. DC dependence on wheel flat depth and crack length (crack depths are not estimated since their measured values were by almost 5 times lower than permissible) at WILD Danger 0 (see Fig. 13 and 14) and Danger 1 (see Fig. 15 and 16).

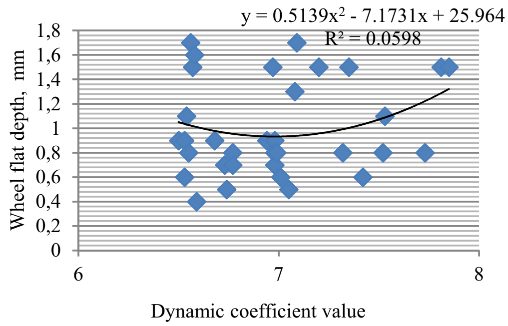

Fig. 13. Dynamic coefficient dependence on wheel flat depth (WILD Danger 0).

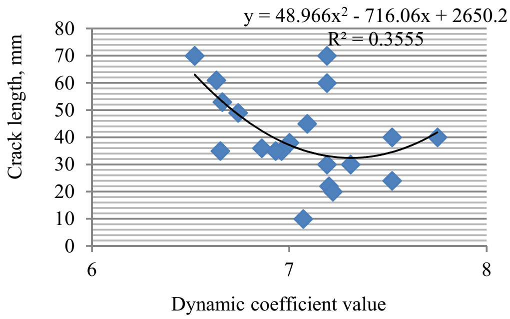

Fig. 14. Dynamic coefficient dependence on crack length (WILD Danger 0).

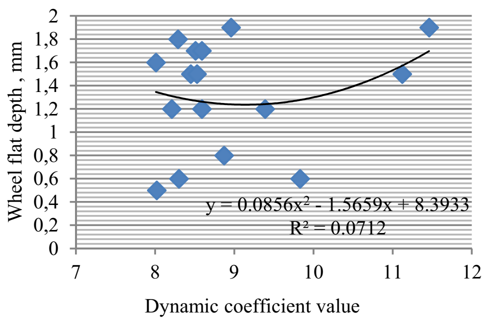

Fig. 15. Dynamic coefficient dependence on wheel flat depth (WILD Danger 1).

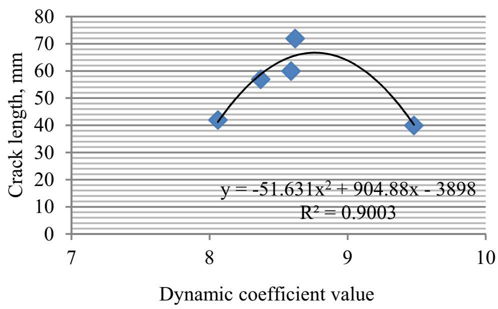

Fig. 16. Dynamic coefficient dependence on crack length (WILD Danger 1).

According to the dependences plotted in Fig. 13 and Fig. 15, a conclusion is to be drawn that the determination coefficient of DC dependence on wheel crack depth is very low, i. e. varies from 0.06 up to 0.07.

According to the dependences charted in Fig. 14 and Fig. 16, a conclusion is to be formulated that the determination coefficient of DC dependence on wheel crack length is quite high, i. e. fluctuates from 0.35 up to 0.90.

5. Conclusions

1. The operation reliability of Wheel Impact Load Detector system comprising up to 99%, i.e. 99% of detected wheel-set failures were confirmed. So, this system enough strongly assures the train traffic safety.
2. Reliability of confirmation of Wheel Impact Load Detector system fixed failures according to the limit of wheel defects values is just 45%.
3. Freight wagon wheel flats account for 64% and wheel running surface cracks for 35% of total wheel failures has been observed in Lithuanian Railways.
4. Regularity of distribution of wheel failure types does not depend on the position of a wheel-set in a freight wagon bogie.
5. Dynamic coefficient values fixed by Wheel Impact Load Detector are higher by 1.5 times in an empty wagon than in the loaded one under the train running equivalent conditions.
6. For the further research, it is necessary to revise the methods of Dynamic coefficient definition, on order to assess the loading level of a freight wagon.

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