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ASSESSMENT OF NEGATIVE EFFECTS OF A COACH RUNNING WITH THE WHEEL-FLAT ON A TRACK BY MEANS OF SIMULATION COMPUTATIONS

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Abstract

The objective of this paper is focused on the computer modelling and dynamic simulation of a coach with damaged wheel and the assessment of these negative effects on a track. The article is composed of two parts. Firstly, problems about the operation of rolling stocks with damaged wheels are described. There are also mentioned diagnostic systems installed on a track for detection and assessment their negative impacts on a track. The second part of the article is dedicated to computer modelling of a coach running on a railway track with the damaged wheel, in this case with the wheel-flat. For these purposes the virtual model of a coach were created. After simulations of its running there were performed analyses needed for the evaluation of its negative impacts on a railway track.

Key words: coach, wheel-flat, simulation computations, dynamic analysis

1. INTRODUCTION

During a rolling stock running on a railway track, conditions in the contact of wheel and rail can cause the derailment of a wheel-set and so the whole rolling stock [2]. This occurs as a result of a surface roughness on a wheel or rail [31]. Roughness is often of jumping type: wheel flats, cracks and rail couplings (Fig. 1).

Fig. 1. Wheel-flat on a wheel surface

This type of wheel damage occurs, when a wheel locks and slides along a rail because of malfunctioning brakes or because the braking force is much higher in relation to the available friction in the wheel/rail contact [9, 16, 17].

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, vertical forces may increase up to ten and more times, thus causing serious damage of rolling stock and a track and enhancing risk to the safe train traffic [22]. With increasing vehicle velocity, dynamic forces cause by these disturbances increase as well [24]. Therefore, it is necessary to identify these said faults of rolling stocks 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 a train motion speed covers several milliseconds or even less.

2. FACILITY FOR DAMAGED WHEEL DETECTION

Due to the negative effects of a rolling stock running with damaged wheels on a track the system “WILD” (Wheel Impact Load Detector) was developed. It is able constantly measure the vertical wheel and rail interaction force of a rolling stock running through the overall wheel perimeter [24].

Fig. 2. Wheel Impact Load Detector layout

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 [19, 21]. The basic component of a WILD system is the track mounted sensor array (see Fig. 2).

There are two basic types of sensors: original sensors are based on strain gauges and measure forces and the new type is based on accelerometers and measures a rail motion (Fig. 3).

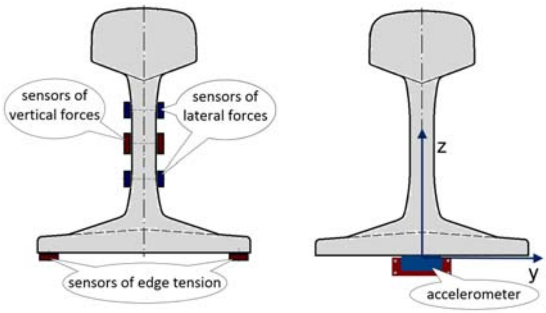

Fig. 3. Original layout (left) and accelerometer layout (right) of WILD system

The sensors are installed at strategic places along a track to monitor passing trains to investigate specific safety related symptoms.

The installation of WILDs does not require the radical modification of an 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 analyse 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 [7]. 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 (Fig. 3 left), 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 (Fig. 3 right). 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 [6, 13, 14].

3. COMPUTER MODELLING THE COACH WITH THE WHEEL-FLAT

The computer model of a coach was set up in Simpack package. It is a multibody software, which allows to create subsystems of rolling stocks [4, 14, 23, 25], whole rolling stocks and even trainsets. During a rolling stock modelling process there is possible to specify damaged wheels.

As an analysed rolling stock the coach with four wheelsets was chosen.

All wheelsets have the same profile and there are guided by the swinging arms in bogies. Between wheelsets and bogie frame the primary suspension is mounted and the coach body and bogies the secondary suspension system connects.

The coach was modelled by fifteen rigid elements. Seven bodies represent dominant weight of the coach and corresponding to the body, two bogies and four wheelsets. The remaining eight bodies represent axle boxes, which have much smaller weight in comparison with other bodies, but they also influence to dynamical properties of the coach by interconnection with each other’s.

In Simpack a hierarchy of the computer model of a coach consists of three subsystems – two bogies and a coach body. Each subsystem is an assembly of several structural elements except of the body of coach which is created as one complex element with prescribed properties [3, 11, 20, 27, 28].

The bogie model is created from rigid bodies connected by force elements, joints, constraints, etc. [10, 29, 30].

For the model creation the definition of all parameters is necessary. During the computer model preparation is important to define coupling between individual subsystems and locations of action forces. This model is prepared for simulations and calculations. The dynamic model of the analysed coach is shown in Fig. 4.

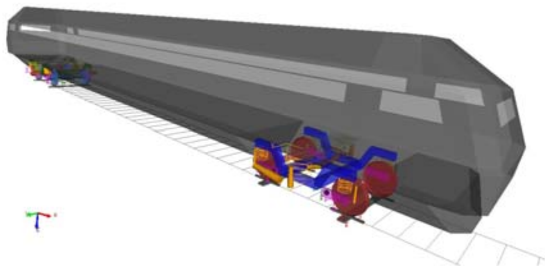

Fig. 4. Dynamic model of the analysed coach in Simpack

Considering the model of the wheel which profile is modelled with untrueness demands different approach to the numerical model in wheel/rail contact [6, 7, 8, 9, 10]. Including untrueness means that the nominal radius of a wheel radius varies with the wheel rotation angle. In Simpack there are three ways for defining the wheel untrueness: radius deviations, Fourier coefficients and harmonic function (simple polygonality) [26].

In our research the radius deviation is considered. In this model, radius deviation is prescribed pointwise in polar coordinates by defined input function. The rotation angle is an independent coordinate and it be defined in the interval [0, 2π] and the radius deviation ΔR or the actual local radius R in meters are dependent coordinates. The mean value is subtracted from the values to get the actual radius deviation [26]. Complete data are splined to allow a continuous interpolation including the derivatives.

The wheel movement with a flat can be described following (Fig. 5). The wheel drops for a distance from point T_1 to T_3 and it induces an impact on the top of rail in point *B* [1].

If we assuming that the wheel-flat length *L* and the wheel radius *R* are constant, the equation of motion can be derived (1):

$$\omega\sqrt{\frac{2\cdot h}{g}} = 2\cdot\arcsin\frac{L}{2\cdot R} - \arccos\left(1-\frac{h}{R}\right) \qquad (1)$$

where *ω* – the rotation speed of a wheel, *h* – the dropping distance of the wheel, *g* – the gravity acceleration, *L* – the wheel-flat length, *R* – the rolling radius of the wheel [1].

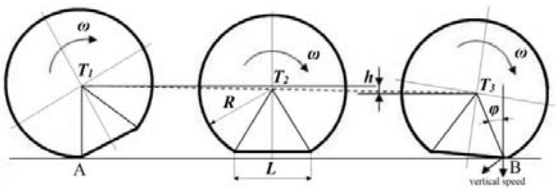

Fig. 5. Impact of the wheel on a rail due to wheel-flat

The impact on a rail is not only from the wheel dropping but also from the vertical speed component. This cannot be neglected. The wheel rotation speed *v* is considerable and therefore it can induce relatively high vertical impact forces. The vertical component of a vertical speed $v_{ver.}$ is expressed as (2):

$$v_{ver.} = \omega\cdot R\cdot\sin\varphi \qquad (2)$$

where *φ* – angle shown in Fig. 5. It is calculated as [15] (3):

$$\varphi = \arccos\left(1-\frac{h}{R}\right) \qquad (3)$$

The wheel-rail impact force that is induced by the wheel-flat at point *B* can be expressed by:

$$F_{impact} = Q\cdot\left(1+\sqrt{1+\frac{2\cdot h+\frac{v_{ver.}^2}{g}}{Q}\cdot\frac{k_p\cdot k_b}{k_p+k_b}}\right) \qquad (4)$$

where *Q* is the static vertical wheel force, which is derived from the total mass of the rolling stock, k_p and k_b are stiffnesses of a rail pad and a railroad bed (i.e. ballast, capping and formation layers), respectively [1].

4. ASSESSMENT OF RESULTS FROM DYNAMIC ANALYSIS

Computer simulations were conducted on the straight ideal track with UIC60 rail profile and with rail inclination of 1:40. Wheels had the S1002 profile. For simulations the elastic track foundation was used, which represents set of a rail body and rail sleeper (Fig. 6).

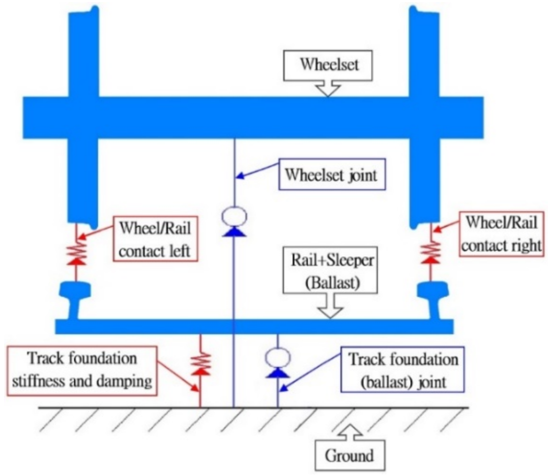

Fig. 6. Elastic track foundation in Simpack

Parameters defining the elastic track model for simulations foundation are:

- effective mass of the ballast and the two rails [kg],
- roll moment of inertia [kg.m^2],
- total vertical track stiffness [N/m],
- total lateral track stiffness [N/m],

- total vertical track damping [Ns/m],
- total lateral track damping [Ns/m],
- and roll track stiffness [Nm/rad].

The coach was run gradually at various speed from v = 10 km/h up to v = 160 km/h with the step of 5 km/h in compliance with the appropriate sampling frequency. Hence there were assessed altogether 32 simulations and from them there were selected only such in which the most significant effects on the track can be observed (Fig. 7 and Fig. 8).

Let’s have a look at Fig. 7. It shows waveforms of vertical wheel forces for speed of 10 km/h, 15 km/h, 20 km/h, 30 km/h, 35 km/h and 40 km/h, respectively depending on travelled distance. Values of vertical forces are small at the speed of 10 km/h and its variation can be practically negligible. Further at the speed of 15 km/h and 20 km/h the wheel-flat impacts on the rail are stronger, indicated by higher peaks in regular intervals.

Figure 8 shows set of other results for the speed of 60 km/h, 80 km/h, 100 km and finally 160 km/h. From this results we can observe, that values of the vertical force for the wheel-flat increase in proportion to speed. If we look at the waveform for 100 km/h, we can see the maximum values (peaks) are not markedly greater in comparison with the speed of 80 km/h, but the investigated mechanical system is more excited.

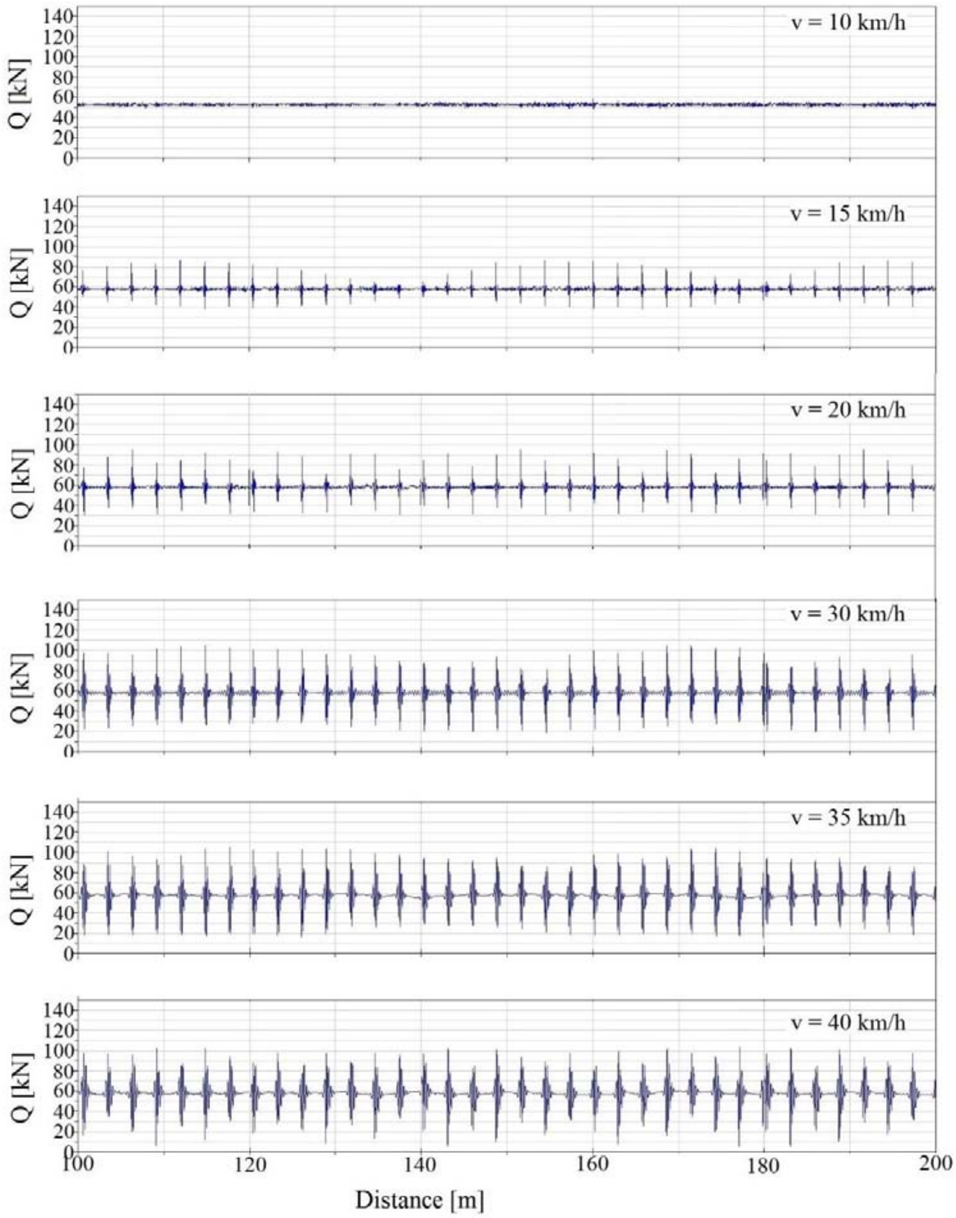

Fig. 7. Waveforms for selected speeds of range from 10 km/h to 40 km/h

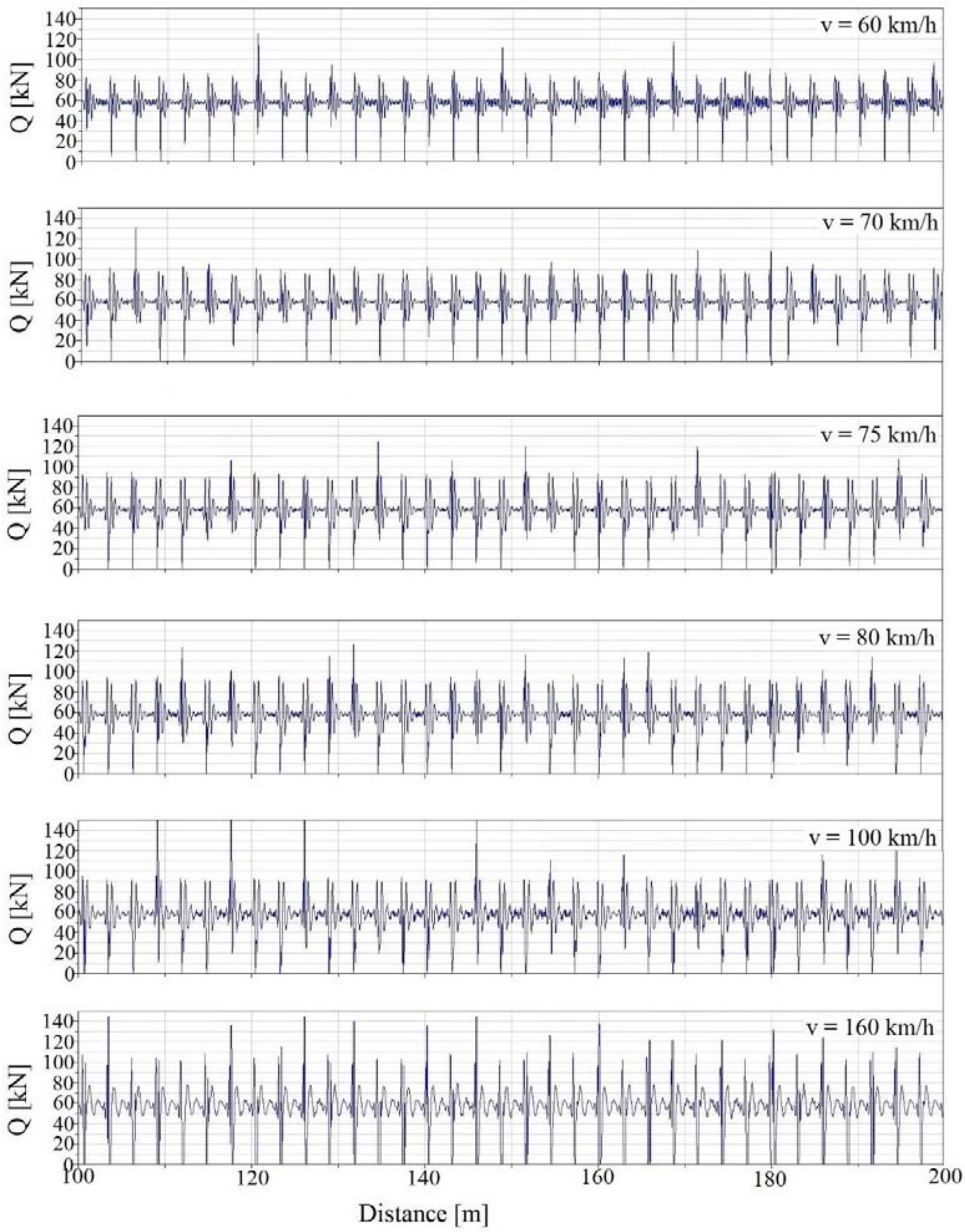

Fig. 8. Waveforms for selected speeds of range from 60 km/h to 160 km/h

It means that also negative effects are more significant. We can suppose that even greater speed of the coach causes heavy negative impacts on the track, as was confirmed in calculations and illustrated by the waveform for the speed of 160 km/h.

5. SUMMARY

This article presents the negative impacts on a track and a way of the computer modelling this phenomenon. The rolling stock running with the wheel-flat causes negative impacts on the track, which means not only significant railway tracks damages but also it can cause destruction of individual parts of rolling stocks structural units. Moreover the passenger ride comfort [18] is degraded. These represent main reasons, why it is necessary to investigate these negative effects in advance. This is possible using the simulation computations. One part of this contribution contains results from numerical simulations of the rolling stock, which wheel is damaged by the wheel-flat. In this work the basic idea and analyses are outlined. The coach was gradually run at the speed form 5 km/h up to 160 km/h. As graphic outputs results from selected simulations are shown and described. In order to reach corresponded results, which could be compared and reliable with results of the measurements, in the future research the track model will be modified according to the real parameters of the investigated vehicle/track system.

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