DETERMINATION OF THE DYNAMIC CHARACTERISTICS OF FREIGHT WAGONS WITH VARIOUS BOGIE

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Abstract. In most cases, dynamic characteristics determine the wagon maintenance cycle, traffic safety, reliability and durability performance. The main dynamic indicators include the vertical K_{vd} and horizontal K_{hd} dynamic coefficients as well as the stability coefficient K_s, which determines the wheel flange resistance to derailment. The article compares dynamic indications for three different types of bogies. There were no tangible differences observed for all the three different types of bogies running at a speed of 40 to 120 km/h on a direct tangent rail section. Nevertheless, there is a realistic potential to improve the dynamic indicators of a freight wagon by rationalising suspension unit parameters.

Keywords: dynamic indicators; bogie; suspension; wagon; model; spring.

Introduction

As we know, dynamic indicators are the main criteria of dynamic characteristics which determine the mode of operation of rolling-stock. They must take into account modern trends in the manufacturing of railway wagons all over the world (Ten, Myamlin 2010) and also meet requirements of normative documents (Normy Dlya Raschyota… 1996). Researchers of many countries have made great efforts in studying the derailment mechanism and train running safety, but the train derailment phenomenon remains far from being resolved and there are still many reports on serious accidents caused by derailment. Therefore, the mechanics of wheel/rail interaction and derailment deserves further investigation in order to guarantee the safe operation of trains (Steišūnas *et al.* 2013). Studies on the subject cover wheel flange climb derailment and wheel impact derailment. First, it is assumed that the wheel flange climb process is quasi-static, then the flange climb derailment criteria are derived through analysing the forces exerted on the wheel-set. The calculations indicate that the results of the classical method are more conservative compared with the results of the analytic method for the diagnosis of wheel-set derailment (Zeng, Wu 2008). Criteria for the evaluation of the safety of railway vehicles in terms

of derailment are reviewed. In the case of quasi-static wheel climb derailment, the current safety criteria are available. Recently, oscillatory wheel load fluctuations of considerable amplitude have been observed on Shinkansen vehicles running at high speed, but there were no established evaluation methods for the dynamic derailment under such a specific condition (Ishida, Matsuo 1999).

In the design of freight wagons, increasingly more attention is given to the task related to engineering development of carriages and assessment of their dynamic characteristics that depend on the type and design, also considering axial loads; and ensuring that dynamic and driving characteristics meet the conditions that influence the track, as well as stability and value of frame forces. A carriage must be universal; its size must allow swapping over carriages in service; it must be fully uniform in respect of parts of the set; both its design and manufacturing technology must be simple (in order to minimise costs of production and maintenance of these carriages); operation must be technically efficient.

The analysis of the impact made by various types of carriages on main dynamic indicators of driving safety of freight wagons, open-top freight wagons in this case, was performed in this paper in relation to the follow-

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ing: vertical dynamics coefficient of the springless part of the wagon K_{vd}; horizontal dynamics coefficient of the springless part of the wagon K_{hd} or the ratio of frame force and static load on the axis; stability coefficient when the flange of the incoming wheel rolls in on the rail K_s.

Usually, when examining the dynamic models of rolling stock, the mathematical relations are presented as multi-functional systems with non-linear relationships. In the article, to simplify the analysis, the linear interpolation method is applied for non-linear relationships in the rolling stock models. This methodology is suitable when limit values of indicators in analysed points are more relevant and their variation patterns in intermediate system states are not as important. In any case, prior to applying the analysis results in practice, they will be experimentally tested.

In the article, the previously developed methodology for the analysis of rolling stock dynamics is simplified, but its scope is expanded for a wider range of objects. Theoretical calculations and mathematical modelling are applied. Results of the analysis results are presented in calculated result tables and graphs.

1. Design Features

For this purpose, three designs of carriages have been analysed: the typical 18-100 model, Western Europe Y25 model, and 18-9771 model with improved characteristics. One of the most common carriages for the 1520 mm gauge area is a two-axle 18-100 model carriage (known as CNII-ChZ until 1972), which is equipped with the following: wedge-shaped movement absorbers, two wheel-sets with hub nodes, two side frames cast of steel with openings for spring sets and hubs, an overspring beam cross-section of a closed-box shape (cast

together with a heelpiece, slide supports, sockets for friction wedges and inflow for the fastening of the bracket of the neutral point of the lever brake gear), and a hinged lever brake gear (Shadur 1980).

The French Y25 type carriage, which is equipped with a bushing suspension, a hard welded H-shaped frame and two wheel-sets with hubs, should be mentioned among the European two-axle carriages of railway freight wagons (Shadur 1980). Each bushing spring set resting on brackets consists of different heights of two cylindrical springs and this design ensures the characteristic of bilinear (two-line) hardness of the spring suspension. A variable-friction vibration absorber, which absorbs vertical and lateral vibrations, is equipped on each hub. The return moment which limits the impact of the wheel-sets is generated at that time. The carriage is equipped with springy slides. The lever brake gear ensures two-way pressure of brake pads on the wheel-set.

Theoretical research on open-top freight wagons manufactured by the CJSC Promtraktor-Vagon (Kanash Town, the Chuvash Republic, the Russian Federation, *http://www.promtractor-vagon.ru*) was performed in order to obtain an in-depth assessment of the dynamic characteristic of freight wagons that use carriages of various designs.

18-9771 model carriage, a new development of the factory (Ten 2009), which has an increased inter-repair distance run of 500000 km (Table 1), was used as the chassis. The design of the carriage enables reducing the dynamic impact of the wagon on the track owing to the spring set with static bend increased up to 68 mm, which allows enhancing the stability of rolling stock, and cutting operation and repair costs of the chassis owing to the use of replaceable friction-resistant elements in friction nodes.

Table 1. Main parameters and dimensions of the 18-9771 model carriage

Main parameters and dimensions	Value*
1. Maximum calculated static load from the wheel-set on the rails [kN] ([tf])	230.5 (23.5)
2. Design speed [km/h]	120
3. Carriage base [mm]	1850
4. Weight of one assembled carriage, maximum [kg]	4900
5. Distance between the level of railheads and the level of supporting surface of the heelpiece in the release position [mm]	811
6. Distance between the longitudinal axles of the side slides [mm]	1524
7. Distance between the longitudinal axles of the spring sets [mm]	2036
8. Static bend of the spring suspension under maximum permissible load, gross [mm] maximum	68
9. Static bend of the spring suspension under packing [mm] minimum (at 60 kN load from the wheel-set towards the rails)	12

10. Conditional friction coefficient of the friction vibration absorber in the spring suspension:
  – under maximum permissible load, gross;
  – under packing
	0.08–0.12
	0.10–0.16

11. Diameter of the location of the heelpiece, maximum [mm]	304
12. Depth of the location of the heelpiece, maximum [mm]	30
13. Insertion clearance according to the Standard GOST 9238-83	02-VM

Note: * Permissible deviations of the parameters and dimensions are specified in the design documents.

The new design of the two-axle carriage of freight wagons features many distinguishing characteristics compared to products developed by other manufacturers, including the following:

– strengthened structure of the side frame;
– use of a vacuum-film steel casting technology for the manufacturing of the side frame and overspring beams;
– increased static bend of the springs of the central spring suspension;
– constant-contact slides;
– use of replaceable friction-resistant hasps in friction nodes.

Calculations of the dynamic quality indicators for loaded freight wagons driving along a straight section of a road within a speed range of 40–120 km/h at 600 m radius curves when the external rail increases by 150 mm within a speed range of 40–100 km/h were performed by researchers of Dnipropetrovsk National University of Railway Transport Named After Academician V. Lazaryan (Ukraine), scientists of Vilnius Gediminas Technical University (Lithuania) and specialists of Promtraktor-Vagon (Russian Federation) using the programming complex DYN-RAIL 'Wagon Dynamics (Single Wagon) 10-12-2007' (Myamlin 2002, 2003) on the basis of relevant normative documents (Normy Dlya Raschyota… 1996). Dynamic unevenness of rails (Fig. 1), specially generated in accordance with statistical characteristics of real railway sections, was used as an actuation in all cases. Theoretical assumptions are presented in (Lingaitis *et al.* 2008).

The parameters of horizontal unevenness are set in parallel to the vertical one. The difference between vertical and horizontal unevenness is presented provided that there is no end-to-end unevenness in the list of possible horizontal unevenness (Dailydka *et al.* 2008a, 2008b; Myamlin 2002).

The vertical profile standard used for the modelling of the rolling stock dynamics is presented in Fig. 1.

Some of the results of theoretical research are presented in charts (Figs 2–6) and Tables 2–4.

With a view to simplify the estimation of dynamic qualities of a wagon, and enhance the universality of the methodology, the authors are proposing a simplified estimation method and provide a sample of estimation.
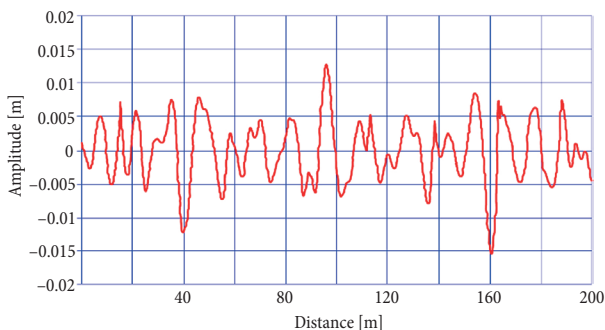

Fig. 1. Vertical unevenness of the rail obtained by modelling

2. Estimation of Dynamic Qualities of a Wagon

For the estimation of dynamic qualities of a wagon and its impact on the track, when moving on rectilinear sites of the track, the following dynamic parameters (symbols for the mathematical model are used in usual presentation) are determined:

1. The vertical dynamics coefficient of an unsprung part of the wagon on forces in axle-box suspension is determined as the ratio of a dynamic makeweight of the vertical force in one axle-box spring suspension to the static pressure of the wheel on the rail P_{ss}:

$$K_{vd} = \frac{S_{Bzimj}}{P_{ss}};\qquad(1)$$

where: K_{vd} – the vertical dynamics coefficient of an unsprung part of the wagon; S_{Bzimj} – dynamic makeweight of the vertical force [N]; P_{ss} – axle-box spring suspension to the static pressure of a wheel on the rail [N].

2. The horizontal dynamics (Kisilowski, Zalewski 2008) coefficient of an unsprung part of the wagon on forces in axle-box suspension is determined as the ratio of the sum of horizontal cross-section forces in axle-box spring sets of one wheel-set (frame force H_{hc}) to the static axial loading $P_{sa} = P_{ss}$:

$$K_{hd} = \frac{\sum\limits_{j=1}^{2} S_{buimj}}{2P_{ss}} = \frac{H_{hc}}{P_{sa}};\qquad(2)$$

where: K_{hd} – the horizontal dynamics coefficient of an unsprung part of the wagon; S_{buimj} – horizontal cross-section forces in axle-box [N]; H_{hc} – the sum of horizontal cross-section forces [N]; P_{sa} – the static axial loading [N].

The directing forces are determined as a product of the total vertical force of an interaction between a wheel and the rail by a tangent of an angle of inclination of a wheel thread to the track plane:

$$H_{himj} = \left(S_{Bzimj} + P_{ss}\right)\cdot \text{tg}\alpha_{imj};\qquad(3)$$

where: H_{himj} – the directing forces [N]; $S_{Bzimj} + P_{ss}$ – total vertical force of interaction between a wheel and a rail [N]; $\text{tg}\alpha_{imj}$ – a tangent of an angle of inclination of a wheel thread to a track plane.

3. The coefficient of stability of the wheel-set against derailment:

$$K_s = \frac{\text{tg}\beta - \mu}{1 + \mu\text{tg}\beta} \cdot \frac{P_v}{P_l} \geq K_{s\,allowable},\qquad(4)$$

where: K_s – the coefficient of stability of the wheel-set against derailment; β – the angle of inclination of the generating cone-shaped surface of a wheel flange with a horizontal for wheels with a standard profile $\beta = 60°$; μ – the coefficient of friction of surfaces of wheels and rails assumed as $\mu = 0.25$; P_v – the vertical load of the leading wheel on the rail [N]; P_l – the lateral effort of interaction of the leading wheel flange with the top of the rail [N]; $K_{s\,allowable}$ – the allowable value of the stability margin coefficient.
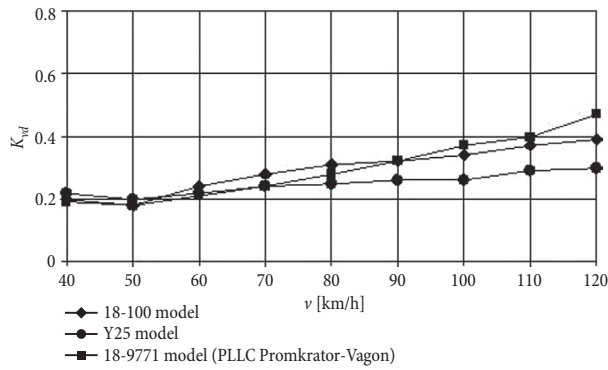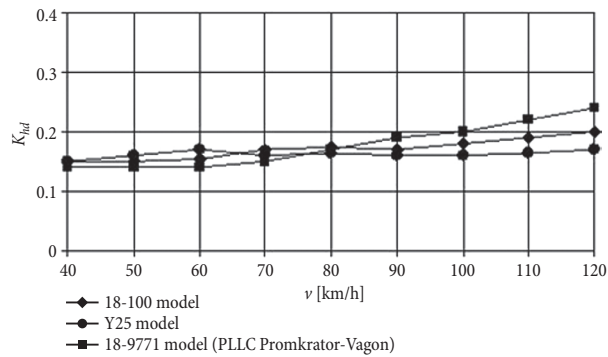
Fig. 2. K_{vd} values (straight line of railway)
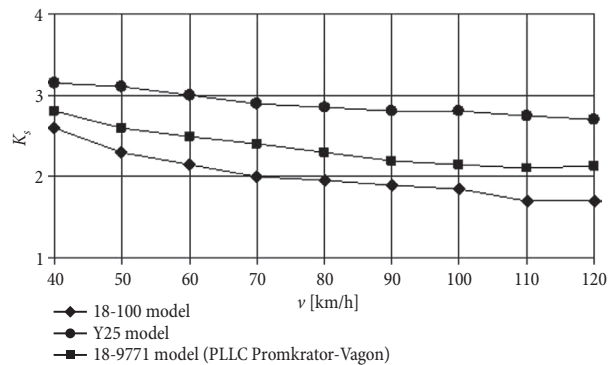

Fig. 3. K_{hd} values (straight line of railway)

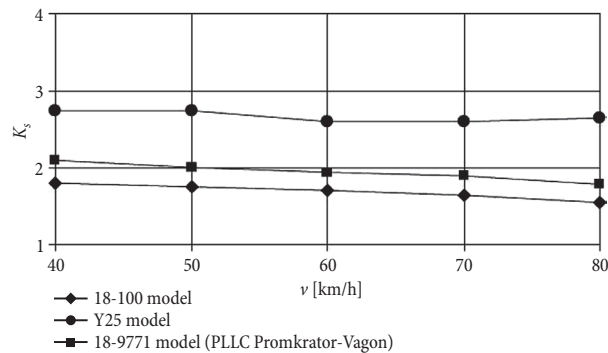Fig. 4. K_s values (straight line of railway)

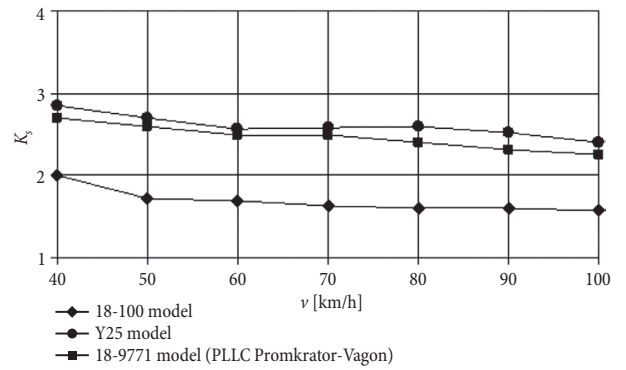Fig. 5. K_s values (curve $R = 300$ m)

Fig. 6. K_s values (curve $R = 600$ m)

Table 2. K_{vd}, K_{hd} and K_s values for various carriages in a straight section of a road at a speed $v = 120$ km/h

Dynamic indicators of driving safety	18-100 model carriage	Y25 model carriage	18-9771 model carriage
K_{vd}	0.39	0.30	0.37
K_{hd}	0.20	0.17	0.24
K_s	1.70	2.70	2.15

Table 3. K_{vd}, K_{hd} and K_s values for various carriages in a $R = 300$ m radius curve at a speed $v = 80$ km/h

Dynamic indicators of driving safety	18-100 model carriage	Y25 model carriage	18-9771 model carriage
K_{vd}	0.70	0.60	0.52
K_{hd}	0.30	0.27	–
K_s	1.55	2.65	1.79

Table 4. K_{vd}, K_{hd} and K_s values for various carriages in a $R = 600$ m radius curve at a speed $v = 90$ km/h

Dynamic indicators of driving safety	18-100 model carriage	Y25 model carriage	18-9771 model carriage
K_{vd}	0.44	0.39	0.43
K_{hd}	0.24	0.19	–
K_s	1.60	2.52	2.41

Conclusions

The analysis of the theoretical research allows concluding that the values of dynamic quality indicators K_{vd}, K_{hd}, and K_s are different for all models of carriages of open-top freight wagons within the limits of requirements specified in normative documents and do not exceed maximum permissible values.

1. Values of the vertical dynamics coefficient of the springless part of a wagon K_{vd} and the horizontal dynamics coefficient of the springless part of a wagon K_{hd} are practically the same for all the three models of carriages in a straight section of a road (Figs 2, 3) within the entire analysed speed range. Some of the excesses of K_{vd} and K_{hd} values of a new carriage at a speed of 90 km/h (Table 2) are explicable by the fact

that it is calculated for a 23.5 tf load on the axes. It is noteworthy that the highest K_{vd} and K_{hd} values do not exceed maximum permissible values, 0.8 and 0.38, respectively, in all sections of the road within the whole speed range analysed.

2. We can see from the comparison of the values of the stability coefficient when the flange of the incoming wheel rolls in on the rail K_s in all sections of a road that K_s for a new carriage is (Figs 4–6) within the permissible limits (Tables 2–4) and satisfies the requirements of norms (Normy Dlya Raschyota… 1996) for freight wagons (Ten, Myamlin 2010; Ten 2009; Myamlin 2002). Similar studies were also performed for other types of models of carriages and freight wagons (Myamlin *et al.* 2005).

3. Generally, the theoretical studies evidence the fact that a 18-9771 model carriage shows better performance with regard to dynamic indicators compared to a 18-100 and Y25 model carriage; however, there is still room for improvement.

4. The analysis of the stability coefficients of vertical and horizontal dynamics values proves that constant-contact slides improve the driving characteristics of freight wagons by reducing the loads that are transferred by rolling stock to the railroad embankment. Thus the results obtained clearly prove not only the possibility to improve the configuration of carriages of freight wagons but also the correctness of the designer decisions as the dynamic indicators of wagons on a new carriage are somewhat better than those of wagons on typical carriages. At the same time, there is room for improvement of the dynamic indicators of wagons on new carriages due to the choice of rational parameters of spring suspension (Lingaitis *et al.* 2008).

5. Based on the methodology described in the article it is possible to evaluate dynamic properties of the newly designed freight wagons and thus make a preliminary assessment of the quality of future wagon even before the production and practical testing phase.

Acknowledgements

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