CALCULATION OF BASIC INDICATORS OF RUNNING SAFETY ON THE EXAMPLE OF A FREIGHT WAGON WITH THE Y25 BOGIE

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Resume

Freight wagons are among the most widely used means of transporting goods by land. Such a number of wagons and transported material and amount of material need to meet requirements in terms of safety and reliability. A wagon bogie is a key element in the wagon running safety point of view. The Y25 bogie is a most used bogie for freight wagons in the region of the central and west Europe. As this bogie was developed several decades ago, it is interesting to evaluate its running properties according to current standards. The presented research brings results of calculation of chosen basic indicators in terms of running safety. The calculations of the freight wagon with the Y25 bogie was performed by means of a multibody model. Simulation computations were carried out for an empty and loaded wagon, which has been running in curves with various radii and at several running speeds.

Available online: https://doi.org/10.26552/com.C.2022.3.B259-B266

Article info

Received 10 January 2022
Accepted 13 April 2022
Online 21 June 2022

Keywords:

Y25 bogie
freight wagon
running safety
multibody model

ISSN 1335-4205 (print version)
ISSN 2585-7878 (online version)

1 Introduction

Recently, large amount of goods is transported by railways. There are relatively many types of freight wagons for transportation of various kinds of goods, e.g. hopper wagons, tank wagons, wagons for transportation of steel coils, intermodal transport, cars transport and others [1-3]. The most of them are equipped by a two-axle bogie. As regards wagons used in the Central and West Europe, there are wagons with the Y25 bogie. Its development dates back to the sixties of the previous century. The objective of this work was to approach some specific features of this bogie and to calculate the basic indicators related to the running safety [4-6]. They must meet the given criteria for safety operation of freight wagons, as well as an entire train set [7-9].

From the historical point of view, the two main lines of development of freight wagons can be recognized. The European line is typical, that these bogies use a primary suspension system and do not have installed the secondary suspension system. The main advantage of these bogies is lower unsprung mass. Usually, the suspension system contains coil springs. On the other hand, the American development line of bogies is characterized that these bogies have higher unsprung mass due to missing the primary suspension system and they are equipped only with the secondary suspension system [10].

The French technical solution of railway freight wagons of the Y type comes from a realization of the primary suspension system by means of a couple of double coil springs, which are placed on a axlebox sides. One of the double coil spring (nearer to a bogie centre) is supplemented with the friction damper (a SNCF Lenoir patent) [10]. Friction force is generated between an axlebox and a guidance. More detailed description of this friction damper can be found below (section 2).

As a railway wagon is subjected to complicated dynamic influences during the operation, dynamic properties of a railway wagon have to be evaluated and investigated in terms of running safety. From the point of view of railway wagons themselves, the main demands are placed on their quality of running and derailment safety [11-13]. The running safety is affected by number of factors, among them are track irregularities, running speed, track geometry, technical conditions of a wagon, the load of wagons and others [14-17].

2 The Y25 bogie

The French national railways initiated the development of the Y25 bogie in 1960. The goal was

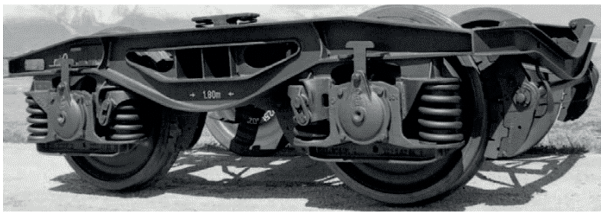

Figure 1 *The Y25 bogie [7]*

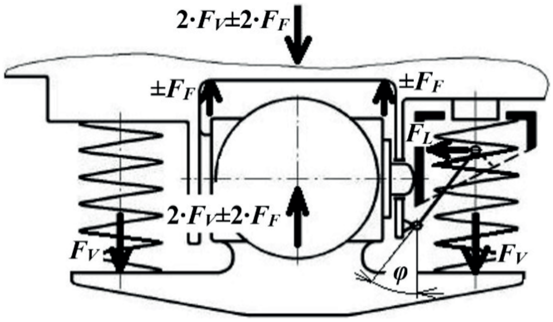

Figure 2 *A scheme of a friction damper [10]*

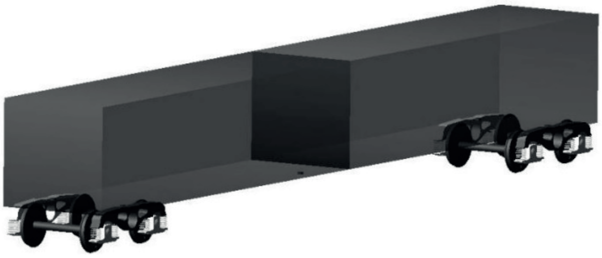

Figure 3 *A multibody model of the investigated freight wagon*

to design a bogie, which would occupate less space and which would have lower weight in comparison to the one used at the time, the Type 931. The efforts resulted in the Y25 bogie. It has the wheelbase of 1800 mm and the wheels' radius of 920 mm. Its suspension consists of duplex coil springs with a bilinear characteristics and they are combined with friction dampers, typical just for this bogie. The body of a wagon is connected with the bogie by means of a central pivot and with a couple of side bearers. The central pivot includes a special pad of a relatively high stiffness. Yaw oscillation of the bogie is eliminated by suspended side bearers. The bogie is usually designed for maximal running speed of 100 km/h at the maximal axle load of 22.5 t (or 25 t) or for the maximal running speed of 120 km/h at the maximal axle load of 20 t [7, 18-19].

The structure of the bogie is typical by the two longitudinal girders and one central lateral girder supplemented by ending lateral supports. Increasing demands on the noise level, total weight of wagons, running safety and others led to a modified Y25 bogie design, which does not use ending supports. Therefore, one can meet recently two basic bogie frame designs. An example of the Y25 bogie is shown in Figure 1.

A vertical load of the bogie is absorbed by vertical coil springs. The friction damper works on the principle of the Lenoir link. The Lenoir link ensures a generation of a friction forces between friction surfaces of an axlebox and a guidance. In this type of a bogie, the values of these forces depend on operational load of a freight wagon, thus on the load of the system (fully loaded, partially loaded) [20-22].

A scheme of the friction damper is shown in Figure 2. The friction damper is composed of an axlebox and a guidance.

If one considers that the force F_L acts in the Lenoir link, the force of one friction couple F_F is given as following:

$$F_F = F_L \cdot f = F_V \cdot f \cdot \tan\varphi \,, \qquad (1)$$

where F_V is the force in a coil spring, f is a friction coefficient and φ is an angle of a Lenoir link inclination. However, one axlebox includes two friction couples, therefore, the total force for one axlebox is doubled [23-24].

The friction forces in the friction damper are described by the Coulomb friction law. However, this formulation often leads to numerical problems during the simulation computations due to a discontinuous course of the force. Hence, the force is modelled as a continuous function.

3 Computer simulation of a freight wagon

A computational model of a freight wagon and simulations of its running on a track have been performed by a multibody software. A complex multibody model is described by differential-algebraic equations (DAE) [25-28].

A virtual multibody model (Figure 3) of a freight wagon consists of three subsystems:

- A front bogie (Y25 bogie),
- A rear bogie (Y25 bogie),
- A wagon body.

During the modelling of a freight wagon in a multibody software, it is necessary to pay attention to proper locations of individual components of a wagon [29-30]. Components are located in these positions

***Table 1** Parameters of bogie components*

Bogie components	m [kg]	I_{XX} [kg·m^2]	I_{YY} [kg·m^2]	I_{ZZ} [kg·m^2]
Frame	2220	1975	1560	2850
Wheelset	1300	688	688	100
Axleload	20	5	5	5

***Table 2** Parameters of suspension components*

Suspension components	k_X [N/m]	k_Y [N/m]	k_Z [N/m]
Coil springs	700000	700000	500000
Centre pivot	$6 \cdot 10^6$	$6 \cdot 10^6$	$6 \cdot 10^6$
Sidebearers	$3.1 \cdot 10^5$	$5.8 \cdot 10^3$	$1.9 \cdot 10^5$

***Table 3** Parameters the freight wagon*

Wagon body	m [kg]	I_{XX} [kg·m^2]	I_{YY} [kg·m^2]	I_{ZZ} [kg·m^2]
Empty	7900	$8.6 \cdot 10^3$	$2.8 \cdot 10^4$	$2.8 \cdot 10^3$
Loaded	40000	$4.8 \cdot 10^4$	$5.1 \cdot 10^5$	$5.0 \cdot 10^5$

to each other and they are interconnected by spring-damper modelling elements. The centre pivots distance of bogies is 15.7 m.

Parameters of individual components of the Y25 bogie, entering to simulations, are listed in Tables 1 and 2.

The body of the wagon has been created by the two rigid bodies connected by torsion spring with defined a torsion stiffness and by rotational joint (with a longitudinal axis of rotation). Parameters are introduced in Table 3.

3.1 Evaluation of the rail vehicles' dynamics

The UIC 518 standard was the first UIC standard describing the running tests of the rail vehicles, which was gradually supplemented [31-32]. This standard has become the basic for European standard 14 363 and other standards and some of its requirements are included in TSI standards. Measurement and evaluation of the vertical wheel forces Q and lateral wheel forces Y are the part of commissioning of new vehicles, according to UIC 518 standard, EN 14 363 standard and TSI [31-32].

Regarding the evaluation of tests of rail vehicles for commissioning, three main areas are defined:

- running safety,
- track load,
- running characteristics and vehicle vibrations.

The running safety is evaluated by several parameters. Quantities, which evaluate forces between a wheel and a rail, can be divided, according to EN 14 363, as follows [31]:

- quantities determining derailment safety:
  - ❑ (Y/Q) - a ratio of a lateral wheel force (Y) and a vertical wheel force (Q),
  - ❑ ($\sum Y$) - resulting the lateral wheel on one wheelset,
  - ❑ lateral acceleration on a bogie frame in a wheelset axis location.

More information regarding the evaluation and commissioning of the rail vehicles are introduced in standards (UIC 518, EN 14 363, TSI).

3.2 Evaluation of a freight wagon dynamics

In this work, the quantities of a freight wagon are evaluated in terms of the running safety, which wagon was analysed in the loaded as well as in empty state at.

The calculation part of the work has consisted of performing the simulation computations in a commercial multibody software. Parameters of the freight wagon have been defined, as it is described in the previous section. Two loading conditions have been modelled, i.e. the empty wagon and the loaded wagon. The entire investigation process of the wanted outputs indicators has been running based on simulations computations. Parameters of the running conditions are described below.

3.2.1 Derailment quotient *Y/Q*

The ratio Y/Q is called the derailment safety and it is one of the running safety criteria. The derailment safety was evaluated for the freight wagon running in a curve with various radii and at various running

Table 4 Maximal calculated values of the derailment quotient Y/Q

Wagon state	R [m]	v [m/s]	Y/Q [-]
Loaded	400	11	0.180
	200	11	0.489
	60	6	0.607
Empty	400	11	0.348
	200	11	0.502
	60	6	0.623

Table 5 Lateral wheel forces between the wheel and a rail

Wheelset 1st Wagon state	R [m]	Lateral wheel force Left wheel [kN]	Right wheel [kN]	$\sum Y$ [kN]	$(\sum Y)_{lim}$ [kN]
Loaded	1000	6.13	5.01	1.12	70.9
Loaded	400	38.56	22.82	15.74	70.9
Empty	200	66.73	32.16	34.58	70.9
Empty	200	22.20	9.25	12.65	18.8

speeds. The limited value of 0.8 is valid for curves with a radius greater than 250 m and the limited value of 1.2 is valid for curves with radius less than 250 m and for superelevation ramps [31-34]. Based on these facts, three different curve radii have been chosen, namely 400 m, 200 m and 60 m. Subsequently, the freight wagon has been running on a track in these curves at speeds of 11 m/s (39.6 km/h) and 6 m/s (21.9 km/h). The values of the derailment quotient have been identified in the PostProcessor of the used software. The obtained values and results of the simulation computations are listed in Table 4.

The values presented in Table 4 indicate that the highest percentage difference of the derailment quotient for a comparison of the loaded wagon and the empty wagon is for the curve of 400 m and the running speeds of 11 m/s (39.6 km/h). This percentage is of 48.28%. Other comparisons bring the percentage of 2.59% for the curve of 200 and the running speed of 11 m/s (39.6 km/h) and finally of 3.37% for the curve of 60 m, but the running speed has been of 6 m/s (21.9 km/h).

Graphs in Figure 4 show waveforms of the derailment safety for an outer wheel of the first wheelset for an empty wagon for running in a curve of 400 m at the speed of 11 m/s. Figure 5 shows a graph of the derailment ratio of an outer wheel of an empty wagon in a curve of 60 m at the speed of 6 m/s and a graph of the derailment ratio of a loaded wagon in a curve of 200 m at the speed of 11 m/s. Negative values of the derailment ratio are caused by an orientation of lateral wheel forces in a global coordinate system.

From values of the derailment ratio (Table 5) one can conclude that the biggest risk of derailment of a wagon during running in a curve occurs on the outer wheel of the first wheelset (in the wagon running direction). This ratio increases with a smaller curve radius. Further, it is obvious that this ratio indirectly depends on the wagon weight, i.e. in the case of an empty wagon running in a curve it is higher than in the case of the loaded wagon in a curve of the same radius. Comparing the Y/Q values for considered conditions one can conclude that the most unfavourable case in terms of safety is when the empty wagon runs in a curve with a small radius.

3.2.2 Sum of lateral forces $\sum Y$

Values of the lateral forces in the wheel/rail contact must be within certain limits.

The results for the limited value for a wheelset depends on an axleload and it is given as following:

$$(\sum Y)_{\text{lim}} = \sum(Y_L + Y_R) = \alpha \cdot \left(10 + \frac{Q}{3}\right)[\text{kN}], \tag{2}$$

where Q [N] is the maximal force on an axle, α is a coefficient and for freight wagons α = 0.85 [-].

An empty freight wagon has a considered axleload of 36.35 kN and for it, the following limit value is valid:

$$(\sum Y)_{\text{lim}}^{\text{empty}} = \alpha \cdot \left(10 + \frac{Q^{\text{empty}}}{3}\right) = 0.85 \cdot \left(10 + \frac{36.35}{3}\right) = 18.8\,\text{kN}. \tag{3}$$

The limit value for the loaded freight wagon by the same manner (the axleload of 220.24 kN) has also been calculated according to the formulation:

$$(\sum Y)_{\text{lim}}^{\text{loaded}} = \alpha \cdot \alpha \cdot \left(10 + \frac{Q^{\text{empty}}}{3}\right) = 0.85 \cdot \left(10 + \frac{220.24}{3}\right) = 70.9\,\text{kN}. \tag{4}$$

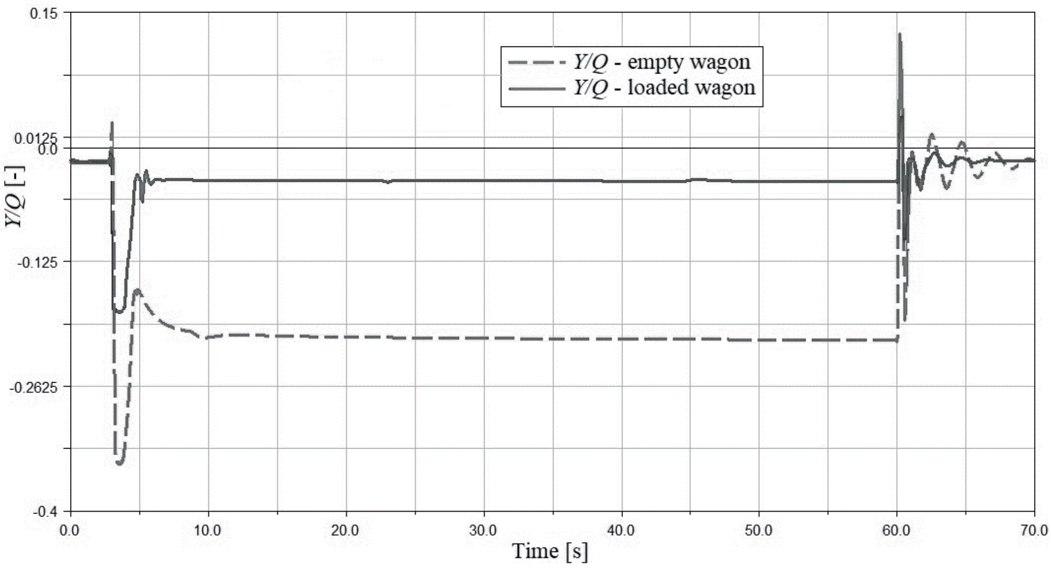

Figure 4 *Derailment ratio - comparison of the loaded and empty wagon, R = 400m, v = 11 m/s*

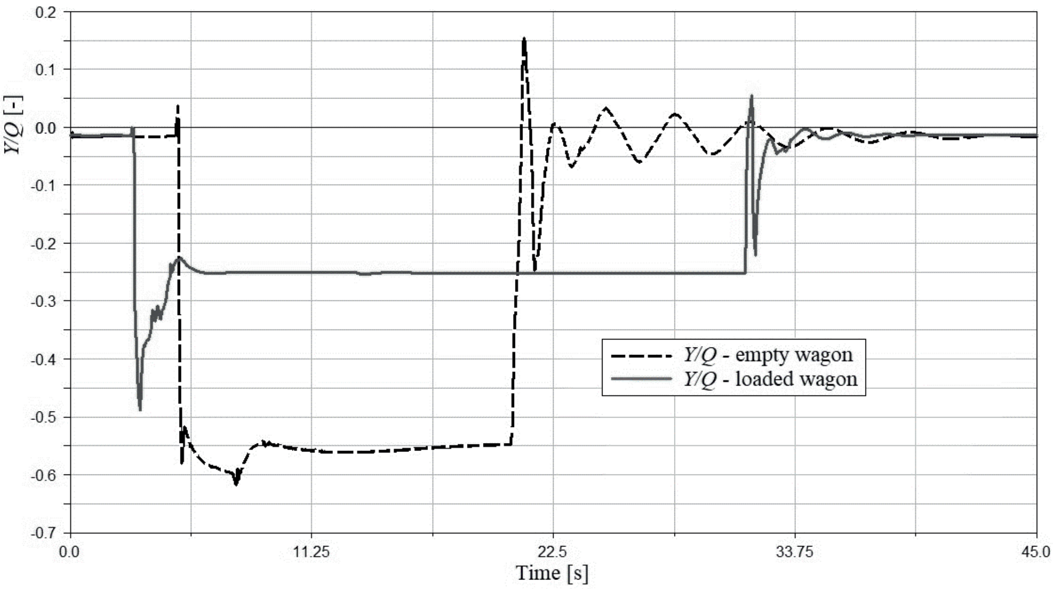

Figure 5 *Derailment ratio for various running conditions: a dashed line - the empty wagon, R = 200m, v = 11 m/s, a solid line - the loaded wagon, R = 400m, v = 6 m/s*

Similar to the assessment of the running safety, several simulation calculations were performed to evaluate the sum of lateral forces for various running regimes. The sum of lateral forces was assessed for the first wheelset in the running direction. These sums were compared to the limited value according to Equations (3) and (4). The results are listed in Table 4. The determined limited values of the sum of lateral forces were not exceeded.

The railway transportation of goods is being and in the future will be needed. It has specifics, which predetermine it for longer distances [35-36]. It is connected with the development of newer and more effective wagons and their structural units [37-42]. Therefore, the future research in this field will be focused on investigation of a wagon under various operational conditions. It will be important to know which operational characteristics will be reached on tracks with a real geometry. It relates to development of other realistic models of railway wagons, which will help to reveal positive properties in terms of operational safety. On the other hand, they will be helpful for indication of negative effects without a risk of damage of a final wagon design directly during the operation [43-48].

4 Conclusion

The article presented evaluation of some parameters of a freight wagon equipped by the Y25 bogie, according to the selected criteria. The research was performed by means of a multibody model and by simulation calculations. The reference freight wagon was tested at various conditions and that for the loaded state corresponding to the maximal axleload of 22.5 t as well as for the empty wagon. The wagon was run in various curves and at various speeds. The wagon properties were assessed based on some criteria introduced on the UIC 518 standard (or EN 14 363).

The derailment safety was evaluated for a wheel with the most unfavourable properties. It is the wheel of the first wheelset in the running direction (an outer wheel). Similarly, the first wheelset has the most unfavourable properties in terms of the sum of lateral forces. Evaluation of results of both criteria has shown that the calculated values did not exceed the limited values.

Acknowledgement

This research was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. KEGA 023ZU-4/2020: "Development of advanced virtual models for studying and investigation of transport means operation characteristics".

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