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LONGITUDINAL DYNAMICS OF THE RAIL VEHICLES

The longitudinal rail vehicle dynamics dealing with the movement disturbance along the railway track are part of the overall vehicle dymamics. Most of the longitudinal dynamics considerations relate to more than one vehicle up to the whole train. The aim of the article are chosen problems of the longitudinal rail vehicles dynamic issues and then more exactly of the train braking. Inextricably linked is the consideration of the inter car push-pull devic-es necessary to cushion shocks of the longitudinal forces during the shunting operations of the freight wagons.

Keywords: rail vehicle, longitudinal dynamics

1. INTRODUCTION

The railway car longitudinal dynamics can be recognized as:
– part of the dynamics related to one railway car or more often more than one car
– issues related to traction (the dynamics of train regarded as rigid subjected to the forces of traction, move resistance and braking)
– dynamics of the multiple cars (mostly considered as one-dimensional dynamics), which can be considered in more detail as:
– dynamics of the wagon during shunting, including the work range of the inter-car buffer
– dynamics of wagon collisions of the trains, also outside the work range of the push-pull devices (crash)
– dynamics of a long train braking and susceptibility to derailment.

The topics were considered in various literature, eg. [2, 3, 4, 5, 7, 13], are shortly overviewed in subsequent chapters, the author investigations begins in [2]. The impact of the longitudinal braking forces are examined in more detail in the [7, 9, 10].

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2. INTER-CAR BUFFERS

Construction and force characteristics of the inter-car buffers are a separate area of the construction of rail vehicles. These devices are produced by competing manufacturers, therefore the access to technical data is difficult. The devices can be build as a part of the central couplers, or side buffers of conventional vehicles. There is no significant difference in the effects of the work of these devices, but there is a big difference in the stability in the lateral and vertical directions along the train caused by impact forces created in these devices.

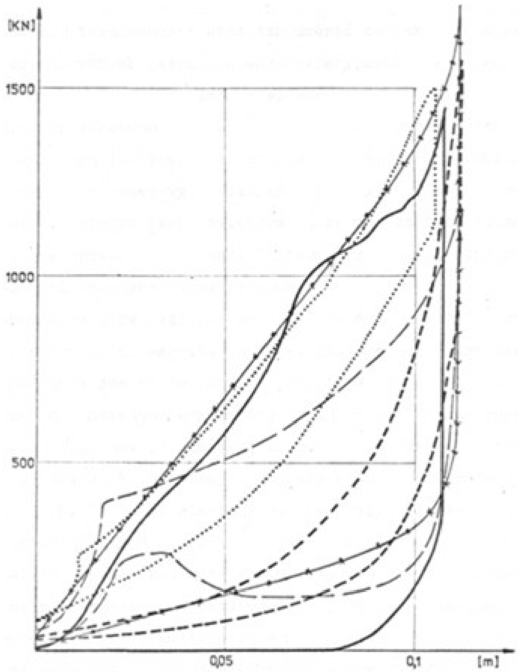

Fig. 1. Static characteristics of the different former buffer types [2]: ____ spring-friction not lubricated, -------- rubber, —x— ring spring, _ __ _ hydro pneumatic, ... elastomer

The primary goal of the use of inter-car buffers is to limit collision forces occurring during the coupling of wagons on the marshalling gravity yard. After first impact with next standing bar, wagon collide with another already shunted cars too with a smaller forces. In order to ensure the reduction of longitudinal forces, inter-car buffer should be characterized by high absorption and then dissipation of the energy. After the action, during release buffer should have a small reaction force, which prevents harmful rejection of wagons. The value of this force must however be sufficient to ensure the proper returning back to the state before compression.

For financial reasons the construction of railway inter-car buffers is usually not complicated. They types of a buffer are: spring collar, elastomer or rubber ring and hydro-pneumatic one. The latter have the most favorable characteristics, but are also the most expensive and require better supervision. Some types are provided with friction cones. Friction elements improve the absorption and dissipation of the energy but cause more abrupt changes in the characteristics of the buffer (train jerking). Older types of buffers were spring bumpers with strong friction elements, but they did not have favorable characteristics. Modern devices contain additionally irreversibly deformable elements absorbing excessive compressive forces.

Detailed modelling of the inter-car buffers should consist of strongly non-linear characteristics of both the pull and push devices. Because the models depend strongly on the characteristics of the type of the buffer, the were modelled separately for each type as shown in the Fig. 2.

a) b) c)

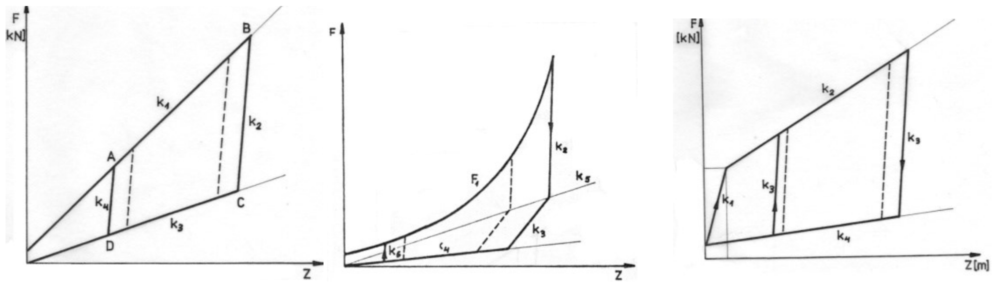

Fig. 2. Buffer modelling: a) ringfeder, b) rubber, c) elastmer [2]

Usually the model of the inter-car device is integrated with the traction devices.

3. THE DYNAMICS OF THE VEHICLE DYNAMICS INCLUDING THE LONGITUDINAL FORCES

The dynamics of the vehicle including the longitudinal forces may relate to a single vehicle or a group of a few wagons.

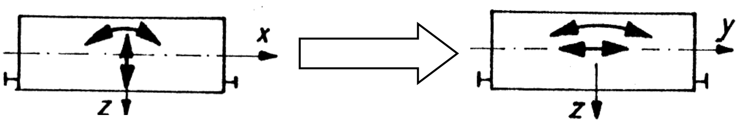

Fig. 3 Transformation of vibration modes in the longitudinal plane [8]

When considering an individual vehicle the longitudinal vibrations may be a serious problem affecting the deterioration of running characteristics due to causing a longitudinal vibration in case of a non optimal design of the bogie: when pitching is not well bumped, it can cause longitudinal vibration of the body of the car (Fig. 3). This phenomenon can be reduced by the proper geometry of the bogie (Fig. 4).

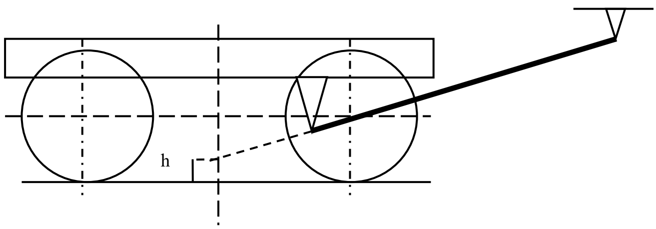

Fig. 4. The pull rod angled to reduce the wheel sets vibration feedback on longitudinal vibrations, height h = 0 disengage these vibrations [8]

This phenomenon can cause deterioration of the running characteristics of the cars and sometimes cause longitudinal waves in the passenger train, appearing particularly during start-up. Some traction units, especially high-speed trains, can be equipped with pairs of longitudinal inter-car dumpers designed to suppress hunting, but reducing the longitudinal vibrations too.

4. TRACTION ISSUES (THE DYNAMICS OF RIGID TRAIN SUBJECTED TO THE FORCES OF TRACTION, MOVE RESISTANCE AND BRAKING)

A specific issue of longitudinal dynamics is the traction movement of the entire train on a particular rail line. The model may be solved by integrating the train way in the speed steps. From the dynamics point of view the simplified dynamic models are used, but additionally they contain the descriptions of the operation of the drive systems, in detail describing the resistance of the train, the route profile and the track arches. This is an important issue for the operation of the trains, but they are not the subject of this publication.

5. DYNAMICS OF THE NUMEROUS WAGONS MOVEMENTS DURING SHUNTING

This part of a few cars' longitudinal dynamics is modelled to analyse the inter-car buffers quality. The time integration method deals with big unlinearity. Normally the train is made up of a large number of wagons, it can be modelled in a simplified way: the individual wagons can be modelled as one dimension systems in the longitudinal direction of the train. There are also models that consider the variation of the cargo or regarding impact of pitching of the whole cars.

In the analyses of the longitudinal train the dynamics the compression of the train – mainly inter-car buffers is also considered, taking into account the non-linearity of elasticity, damping, and hysteresis, but usually only in the longitudinal direction in both: models of side wagon and autocoupler buffers. More accurate model to the real characteristics of buffers can be very difficult to achieve, it requires a description of additional phenomena and is not always accurate. The simplified model diminishing the amount of the wagons and of the buffer is shown in Fig. 5.

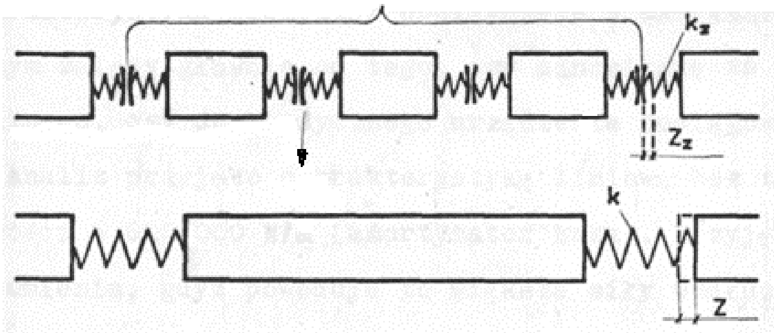

Fig. 5. Simplified number of the cars and if the inter car buffers [2]

Using contemporary fast computer this simplification is less applied.

In the case of automatic couplers special stabilize coupling element joints are used, which reduce the destabilizing influence of the short arms of the coupler in the transverse direction (Fig. 6).

The risk of a loss of directional stability is significant in the track curves for automatic couplers, and for all types of couplings this risk can be caused by an uneven height of the couplings due to unbalanced loading of the wagons (Fig. 6a).

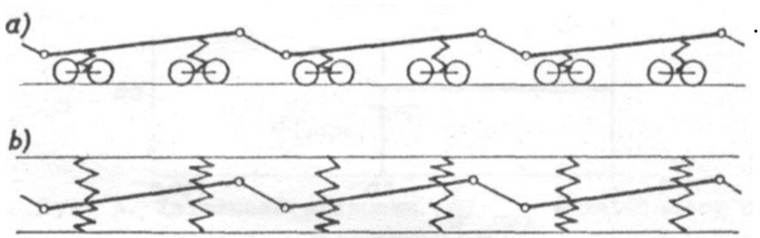

Fig. 6. Forms of longitudinal instability and train a) vertical, b) transversal [2]

The Fig. 7 shows the influence of the type of the inter-car autocoupler on the of transverse forces.

a)

b)

c)

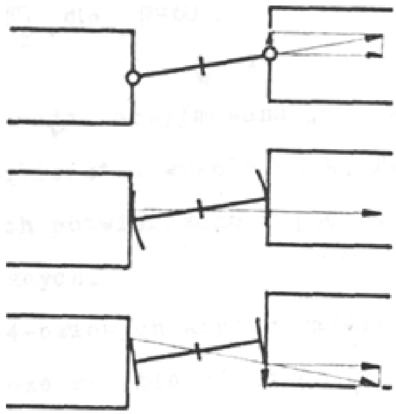

Fig. 7. Types of autocoupler joints: a) bolt, b) rolling, c) shoulder [2]

Joints stabilizers are unsuitable for standard buffers used in Europe, where stabilisation in the transverse direction is achieved by the use of pairs of buffers.

Such problems were investigated by the author in his works. The simulation results obtained in the models of the longitudinal dynamics of the collision of many cars [3, 4] do not differ from the results of other authors.

6. MODELLING OF THE WAGONS PASSING CURVES OF THE TRACK

Analyzes of push-pull devices rarely include the buffer behaviour during the car passing curves on the track. Analysis may include additionally the transversal forces of friction plates in the spherical buffer disc and the friction force in the buffer sheath. The phenomena are highly nonlinear and simulation may be done over time. Presented below is an example of a simulation model a made by the author made for a wagon EW4 and compared with measurements on real cars [12].

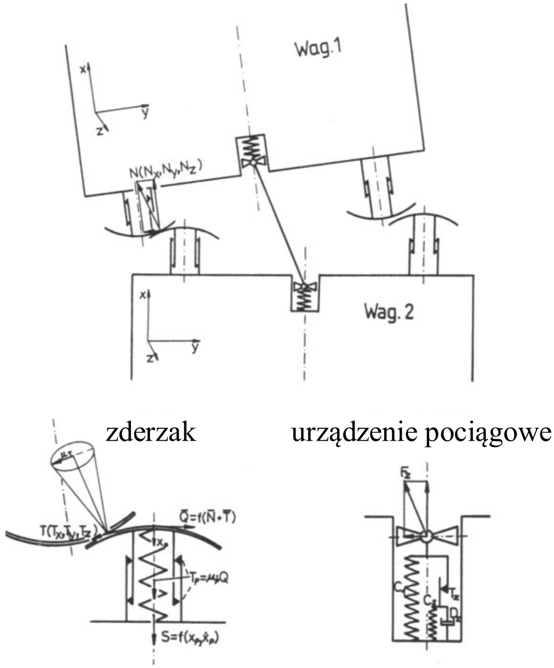

Fig. 8. Model scheme of a fragment of the 3 wagons model of the EW IV [12]

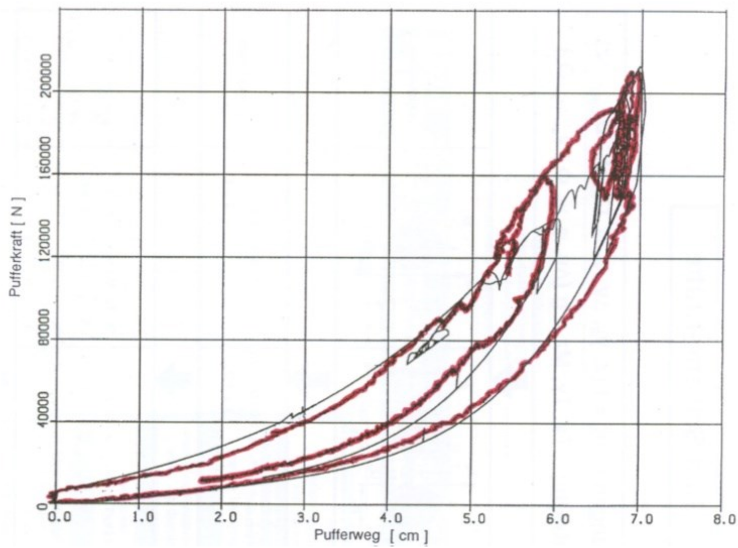

Fig. 9. Characteristics of the buffers of the EW IV car [12], measurement , simulation

7. DYNAMICS OF WAGON COLLISIONS IN THE TRAINS, ALSO OUTSIDE THE SCOPE OF THE WORK OF INTER-CAR BUFFER (CRASH)

This is a relatively new field of longitudinal dynamics, it gained great importance in relation to the passive safety of trains and passengers.

To increase the train security special end faces of cars with buffing elements are constructed. Another method is to strengthen the passenger compartments to improve survival rate of the passengers while making the end zone of the wagon structure more deformable to absorb impact energy e.g. [11].

8. LONGITUDINAL DYNAMICS DURING THE TRAIN'S BRAKING

8.1. Source of the longitudinal forces during braking

Significant longitudinal forces can occur on the train using pneumatic brakes during braking because of their intrinsic qualities:

– train consists of multiple vehicles and the individual vehicles have a certain freedom of movement relative to each other in the longitudinal direction due to the flexibility of the push-pull devices;

– braking of the individual vehicles should be proportional to their weight, but this recommendation is not assured for the normal pneumatic brake;

– braking forces throughout the train are not uniform; in the case of pneumatic brake controlled from a locomotive in the head of the train, in the initial phase of the braking of the wagons at the front the train is stronger than in its end part;

– for iron brake pads commonly used on freight trains the coefficient of friction increases strongly at low speeds.

As a result of these features during the braking of the trains can form the large dynamic longitudinal forces of even more than a million newton. This creates a significant risk to traffic and in the extreme cases could result in the derailment or tear of a train composition. There are also some additional factors affecting the level of longitudinal forces of a braking train like uneven loading of the wagons or initial tension of the train composition before the braking. That is why the longitudinal train forces cause the nesesery reduction of the braking intensity of the train.

This issue affects mainly long freight trains, in the passenger trains have little significance.

The main cause of excessive longitudinal forces are flexible inter-car couplings. Their elasticity is necessary to reduce the forces occurring mainly during the wagons shunting in the marshalling yards to assure a quiet movement of the trains. In UIC countries these cushioning elements are separated:

– buffers take push forces,
– shock absorbers of the screw coupling take the pull forces.

Loose coupling used to facilitate starting of the train composed of wagons with plain bearings used in the old days of steam traction belong now to history. Nowadays, the freight trains are coupled without free play of the buffers and in passenger trains squeezed with a greater preload.

The second cause of longitudinal forces in braked train is the use of pneumatic brake. In this brake the control pulse speeded along the train has a relatively low speed, as thoroughly described in [4, 9]. This causes the initially more intense braking of the train head and causes the striking of the rear part on the front of the train. In case of a large number of wagons of the freight train, their significant masses cause immense braking force and the mentioned initial uneven braking can lead to very large longitudinal forces.

Another cause of considerable longitudinal forces is mostly the variable with speed brake friction coefficient of the braking pads (cast iron pads are still the most widely used abrasive material). At low speeds of the beginning of the braking (of about 20 km/h) the coefficient of friction increases significantly and may cause an extreme situation in the very low speed, when the first cars have already stopped, and the next ones, due to the flexible coupling still move and crash into the standing ones. Due to the friction coefficient variation , the considerable axial forces may be significant. Such situation may lead to derailment of the train. During the test braking of a long train from a small initial speed, a temporary lifting of the end of the wagon was observed.

The dynamics of the train's braking may be analysed using a model of a stiff train or of one equipped with buffers. Model of the stiff train, much simpler, gives results that differ more from reality, but allow more precise description of the effects of the braking process changes. For complete the analysis, the models having the longitudinal dumpers in the a train are used.

The following chapter presents investigations done by the author of the article.

For clarity: the braking position "passenger" (P) means shorter cylinder filling time, position "freight" (G) means longer filling time. Brake pad name is ued for a disc brake, thr name brake shoe is is used for tread brake (braking on running wheel surface).

8.2. Longitudinal train forces in the rigid train model during braking

The considered problem - the pneumatic braking of the train was presented in the examples. Braking characteristics depend largely on the braking position. In position "passenger" (P) the braking distance is shorter, but longitudinal forces in the train are bigger. Figures 10 and 11explained the results.

a) b)

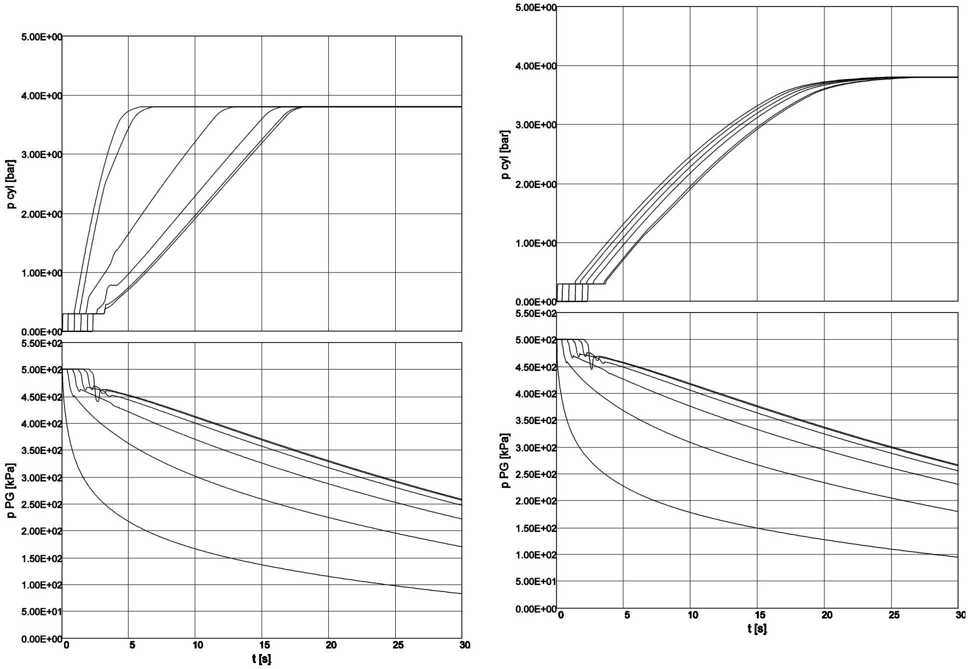

Fig. 10. Pressures in the cylinders and in the brake pipe of the 50 wagons train simulation: a) brake position "passenger" b) brake position "freight"

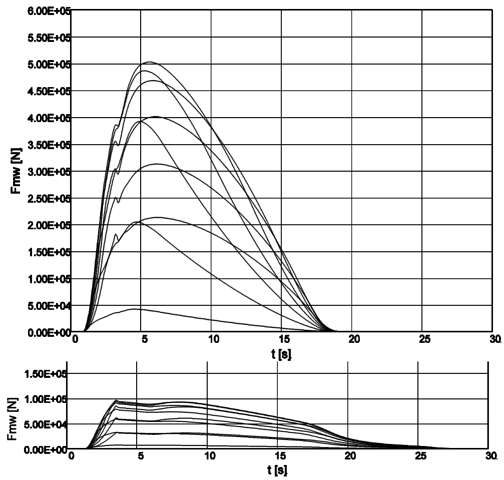

Fig. 11. Simulated course of the train's braking (stiff train model) of the nominal 50-wagons; the longitudinal forces as a function of time; a) brake position "passenger", b) brake position "freight"

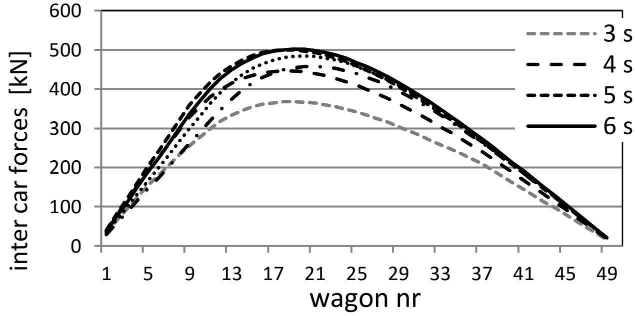

Fig. 12. Course of longitudinal forces during braking as a function of the position of the inter-car coupling in the train at selected time points [2]

8.3. Longitudinal forces in the flexible train model during braking

For selected variants of the train composition the train braking including the longitudinal dynamics has been done. The simulation includes the characteristics of inter-car buffer and draw gear. In modern European freight trains free clearance in the inter car coplings should not be allowed, but it can occur in a careless coupling. Therefore the simulation with the space of 0 m and 0.02 m (Fig. 13) was investigated to investigate the possibility of the train quality deterioration.

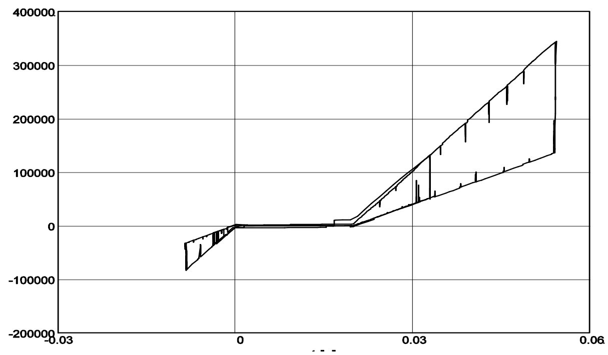

Fig. 13. Characteristics of the push-pull device with the clearance of 0.02 m; obtained in the train simulation; shown a compression-stretch curve between the fifteenth and sixteenth wagon [7]

Let's consider for example the simulation results presented below for a 50-wagon freight train with a brake position "passenger" with cast iron pads or with the disc brakes, from a initial braking speed of 100 km/h and with equal percent of the braked weight of each wagon.

Difference in longitudinal forces in the event of emergency braking the both trains have are not spectacular. This statement is not telling everything. In the case of a disc brake the inter-car forces are not greater for other speeds. Yet in the case of the tread brake the for the low-speed range of the braking beginning of 10 to 20 km/h longitudinal forces augments because of the variation of the friction coefficient as a function of the ride speed.

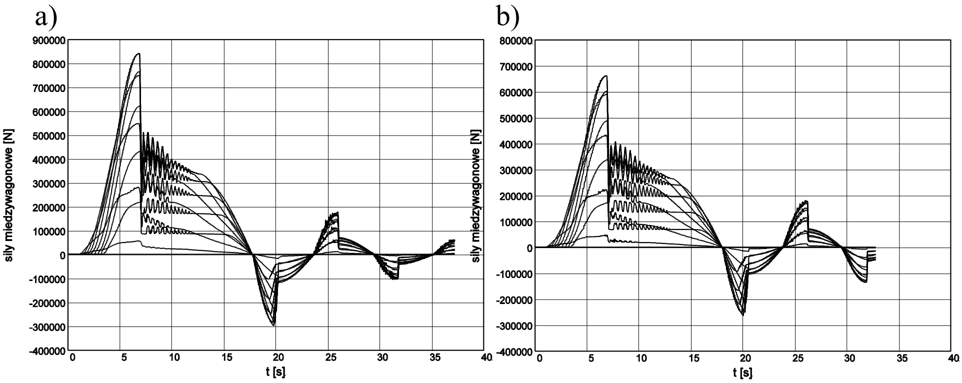

Fig. 14. Longitudinal forces in the freight train of 50-wagons in the brake position "passenger"; train with buffers and: a) disc brake, b) the tread brake. Braking beginning speed is 100 km/h [3]

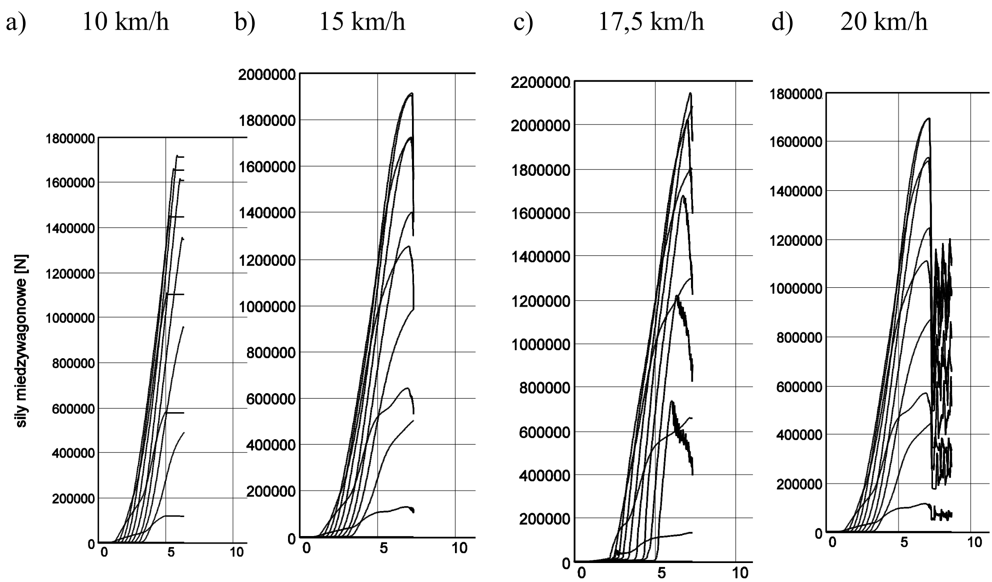

Fig. 15. Emergency braking train of 50 wagons in the brake position of "passenger", equipped with an iron brake shoe; susceptible train with buffer clearances of 20 mm, initial braking velocity of a) 10 km/h, b) 15 km/h, c) 17.5 km/h, d) 20 km/h [3]

Figure 15 shows the emergency brake a train of 50 wagons equipped with a shoe brake from the initial speed of 10, 15 and 20 km/h. The level of the forces in Fig. 15 show derailment risk if the braking was done on a curve. For the long trains equipped with brake position “P” and brake blocks, if there is no risk of accidents, emergency braking starting from low speed (to about 20 km/h) should be avoided.

8.4 Setting the "long locomotive"

An another method for reducing the level of longitudinal forces in a long train is a specific charge cylinder time setting of a freight train is the position called "long locomotive" (somewhat misleading name). It is presented briefly in the [6], and more detailed in [7].

Figure 16 shows the idea of this setting. This brake position allows radical reduction of longitudinal forces (Fig. 17). This however, is more cumbersome to use, since it requires a set brake system of individual wagons before each train composing.

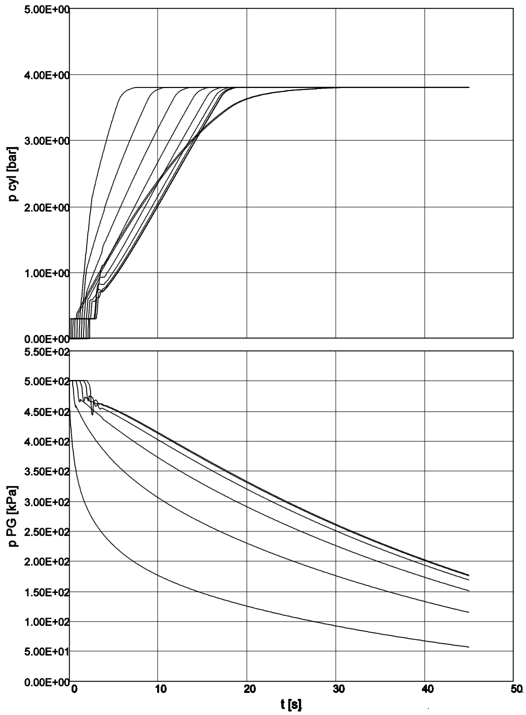

Fig. 16. Pressure in the brake pipe and brake cylinders of the 700 m, 4000 t train with brake system setting „long locomotive”. Presented are the results of every fifth wagon [7]

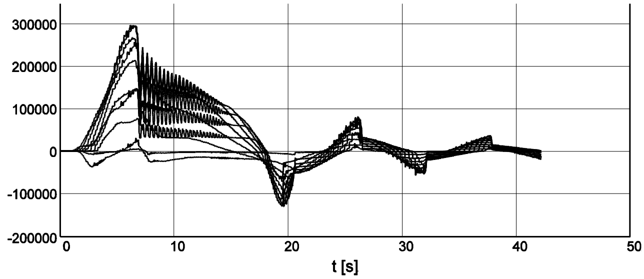

Fig. 17. Longitudinal forces during train braking simulation of the 700 m, 4000 t train braked emergency from 100 km/h with brake system setting „long locomotive". Inter-car buffer without clearance, presented are the results for every fifth wagon [7]

The advantage of this setting is the diminishing of the longitudinal force during the braking of the train. Instead of compression forces it gives tensile forces at the front of the train, which causes a proportionate reduction of the maximum compressive forces.

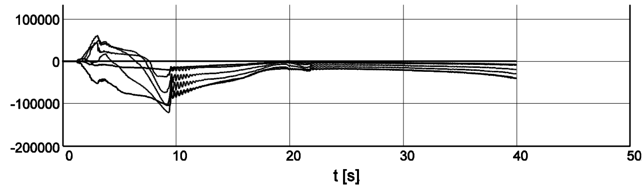

Fig. 18. Longitudinal forces during train braking simulation of the 30 wagon, 434 m, 2400 t train braked emergency from 100 km/h with brake system setting „long locomotive". Inter-car buffer without clearance, presented are the results for every fifth wagon

The braking distance is much shorter than in brake position "G". It is more pronounced for shorter train (Fig. 18). For longer trains the effect of the braking position "long locomotive" is reduced.

9. CONCLUSION

Reducing the longitudinal forces between the cars has various aspects, in the first part of the article the existing problems are reviewed, the second part is dedicated to the impact of braking of the train. The best method of radically reducing the longitudinal forces in the train during braking is introduction of the electric brake control (e.g. electro-pneumatic brake) instead if pneumatic control, but the use of such methods is associated with a significant increase in the price of rolling stock. In practice (mentioned in the article) only the cheaper solutions which do not require the power supply of freight cars are considered.

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DYNAMIKA WZDŁUŻNA POJAZDÓW SZYNOWYCH

Streszczenie

Dynamika wzdłużna pojazdów szynowych zajmująca się zakłóceniami ruchu wzdłuż toru kolejowego jest częścią dynamiki pojazdów. Większość rozważań w ramach dynamiki wzdłużnej odnosi się do więcej niż jednego pojazdu – aż do całego pociągu. Celem tego artykułu jest krótki przegląd zagadnień dynamiki wzdłużnej i bardziej dokładny hamowania pociągu. Wiąże się z tym nierozerwalnie omówienie międzywagonowych urządzeń amortyzujących, koniecznych do zmniejszenia sił zderznych podczas sprzęgania wagonów towarowych.

Słowa kluczowe: pojazdy szynowe, dynamika wzdłużna