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Parametric study of the distribution of longitudinal dynamic forces developed in the train body using hysteretic characteristics of Ringfeder buffers

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Abstract. During braking, due to the interaction between the vehicles, longitudinal dynamic forces, characterized by different values and an irregular distribution along the train, develop in the train body, affecting the passengers` comfort or even the traffic safety. The paper is a parametric study having as objective to determine the influence of the number of coaches, vehicle weight and delay time of the development of braking forces on the size and distribution of the longitudinal dynamic forces developed in passenger trains during braking. The first analysis is based on the change in the number of vehicles which are part of the train. The second case analyzed refers to the total mass of the vehicles, which increases by 50% compared to standard train mass. In the third situation, there are taken into account variations of ± 20% of the length of the train overall pipe that are able to generate delays related to the occurrence and development of the braking forces at each vehicle of the train body.

1 Introduction

In exploitation, the appearance and development of longitudinal dynamic forces are due primarily to the principle of operation of the basic brake, exploitation characteristics of the vehicles forming the train, its length, but especially to the characteristics of buffer and draw-gear devices that equip these vehicles.

Taking into consideration the way the basic brake works (indirect compressed air brake) [1-4], the appearance of longitudinal dynamic forces is influenced by the time when the distributors that equip each rail road vehicle come into action, being commanded by pressure drop along the general pipeline and the propagation speed of the brake wave. Distributors are devices that control the pressure in the brake cylinders according to the lower of the pressure in the general pipe of the train, so, the size of the brake force for each train vehicle. Thus, in the train body, at a certain time, vehicles located in the first half begin to brake, while those from the back of the train do not have the brake force or they have just begun to develop it. This causes collisions between vehicles in the train (longitudinal dynamic forces). Another

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aspect that cannot be neglected is the length of the train that influences, on the one hand, the general pipe length with implications on the delay time in the development of brake force and, on the other hand, it contributes to increase the train weight with influences on the maximum values of the longitudinal forces. The effect of the delayed development of brake forces on the longitudinal dynamic behaviour of the freight trains is approached by Nasr and Mohamadi in the work [5].

The collision devices used in rail vehicles are designed to protect the structure of the vehicles, to diminish the forces between them during braking and to dissipate a part of the energy during collisions [6]. Characteristics and the constructive type influence the development and/or reduction of the longitudinal dynamic reactions with profound implications on the running stability of the vehicles [7]. Also, to study the longitudinal dynamic of the trains in brake, equipped with manual hook-screw-type coupling, the elastic characteristics of these devices must be known.

In this paper, the study of the distribution of longitudinal dynamic forces (forces of compression and tensile) in the body of passenger trains found in brake is done by changing three parameters: the length of the train – by increasing or decreasing the number of wagons (*Nw*), the train weight (*Wt*) –increasing it by 50% and the change of the braking delay time (*Td*) by 20%, with the main purpose to highlight the influences of longitudinal forces.

2 Dynamic System

2.1 Vehicle model

Knowing that the train consists of a locomotive and a finite number of coaches, the model used in the software calculation consists of n rigid bodies representing the vehicles entering in the train composition, connected by elastic and damping elements representing buffer and draw-gear devices.

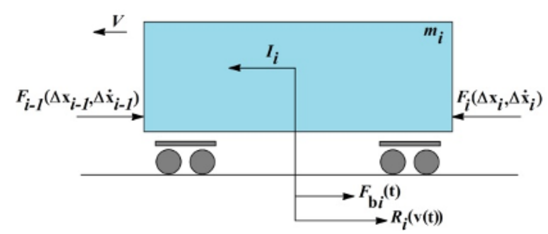

Fig. 1. Forces acting on a vehicle.

At the level of a vehicle in the train body (excepting the first and the last vehicle) the forces that act are: forces of inertia Ii, braking forces $F_{bi}(t)$, resistances to march $R_i(v(t))$ and the forces from buffer and draw-gear devices (from the front vehicle $F_{i-1}(\Delta x_{i-1}, \Delta\dot{x}_{i-1})$ and from the rear vehicle $F_i(\Delta x_i, \Delta\dot{x}_i)$), for i = 1÷ n, where $\Delta x_i = x_i - x_{i+1}$ represents the relative movement from the buffer and draw-gear devices (see Fig. 1).

For the first vehicle there are not forces on buffer and draw-gear devices found in the front of the train, but only on those who come into contact with the next vehicle in the train and at the last vehicle, there are not forces on buffer and draw-gear devices from the back of the train.

Thus, applying the laws of the mechanics, we obtain $n - 1$ nonlinear equations, each describing the movement between two consecutive vehicles.

For a group i of buffer and draw-gear devices (coaches i and $i+1$) the relation that characterize the movement is [8]:

$$\ddot{y}_i = \frac{F_i(y_i,\dot{y}_i) - F_{i+1}(y_{i+1},\dot{y}_{i+1}) + F_{f,i+1}(t) + R_{i+1}(v(t))}{m_{i+1}} + \\ + \frac{F_i(y_i,\dot{y}_i) - F_{i-1}(y_{i-1},\dot{y}_{i-1}) - F_{f,i}(t) - R_i(v(t))}{m_i} \tag{1}$$

It is specified that, in order to simplify the above equations, the notation $y_i = \Delta x_i$ was introduced.

2.2 Model of buffer and draw-gear devices

Mathematical modeling of buffer and draw-gear devices has as main aim the achievement of a functional mathematical model with the help of which to be able to properly evaluate the progress and the size of longitudinal dynamic reactions in the train body during braking.

Consequently, the calculation of the forces for the traction, collision and coupling devices follows the below equation [9, 10]:

$$F(x,\dot{x}) = \begin{cases} k_e \cdot x + k_f \cdot |x| \cdot \tanh(u \cdot \dot{x}) & for \quad x < 0, \\ 0 & for \quad x = 0, \\ k_{ec} \cdot x + k_{fc} \cdot |x| \cdot \tanh(u \cdot \dot{x}) & for \quad x > 0 \end{cases} \tag{2}$$

where x is the stroke and $\dot{x}$ the speed of such devices, k_e and k_f - specific constants for elastic and friction forces that develop in the collision device, k_{ec} and k_{fc} represent specific constants for elastic and friction forces that develop in the traction device, and u is a scaling factor.

2.3 Calculation model of the braking force

To calculate the maximum braking force developed by each vehicle, putting the condition to avoid, under normal circumstances, the lock of the axles during braking actions [7 - 11] it results that the adhesion force between the wheel-rail should not be exceeded, thus:

$$F_{f,i} \le F_a = \mu_{a,i} \cdot m_i \cdot g \tag{3}$$

where μ_a represents the wheel-rail adhesion coefficient, and m_i represents the weight of each vehicle in the train body.

Taking into account the evolution of the pressure from the brake cylinder in addition to the maximum pressure stabilized in it, we can determine the brake force thus [8, 11]:

$$F_{f,i}(t) = \mu_a \cdot m_i \cdot g \cdot \frac{p_{cf,i}(t)}{p_{cf\max}} \tag{4}$$

In the previous relation, $p_{cfi}(t)$ represents the evolution in time of the pressure in the brake cylinder, and p_{cfmax} is the maximum stabilized pressure.

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2.4 Application

In order to point out the influence of parameters *Nw*, *Wt* and *Td* regarding the evolution of longitudinal dynamic forces, as well as the distribution of maximum compression and stretching forces that appear in the buffer and draw-gear devices, the programme created in Matlab was run [8 - 10] where the data from Table 1 were used. It should be specified that the train undergoes emergency braking from top speed of 180 km/h on a railway in alignment and landing so that the only influences that lead to differentiation of results should be introduced only by required parameters.

In the study it is considered that the evolution of pressure in the brake cylinders of all vehicles entering the train composition is made by the same feature and filling time.

Table 1. Numerical model parameters.

The main parameters	Values
The locomotive weight	$m_l = 120$ t
A wagon weight	$m_v = 40 \ldots 60$ t
Constant specific to collision devices	$k_e = 2.8 \cdot 10^6$ N/m
	$k_f = 1.4 \cdot 10^6$ N/m
Constants specific to traction and binding devices	$k_{ec} = 5.46 \cdot 10^6$ N/m
	$k_{fc} = 2.43 \cdot 10^6$ N/m
Maximum pressure in the brake cylinder	$p_{cf\max}$=3.8 bar
Wheel-rail adhesion coefficient	μ_a=0.1

The value of the pressure developed in the brake cylinder necessary to calculate the brake forces was experimentally determined in laboratory specialized stand, using distributors from passenger vehicles used in mining.

3 Results and discussions

In order to start, it is analyzed the influence of *Nw* parameter on the distribution of longitudinal forces of compression and tensile in the train body. The results are shown in Figures 2 and 3.

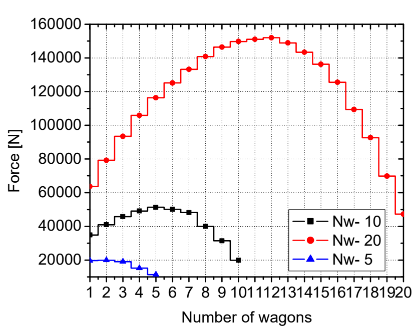

Fig. 2. Distribution of compression forces according to *Nw* variation.

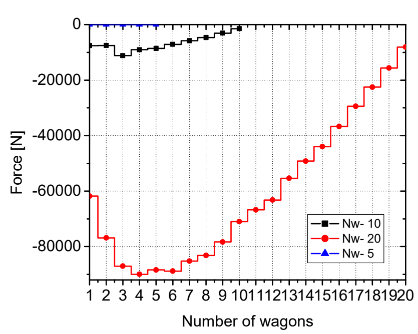

Fig. 3. Distribution of tensile forces according to *Nw* variation.

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Doubling the number of coaches, starting from the model train composed often wagons and an engine [8], leads to triple compression forces (see Fig 2). The maximum force has a displacement towards the second half of the train (coupling nr.12) in relation to the standard train, where the maximum force is on coupling no. 5 at the half of the train. The tensile forces grow very much highlighting the phenomenon of recoil after equalizing the brake forces on the vehicles (see. Fig. 3).

Reducing *Nw* to half shows a significant decrease of compression forces by about 60%, totally modifying the allure of distribution curve. The maximum compression in this case is registered on the first two collision devices. Tensile forces, in this case, are practical void the train shows no rebound (Fig.3).

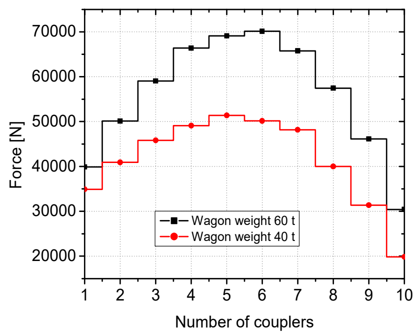

Fig. 4. Distribution of compression forces to increase the weight of a wagon by 50%.

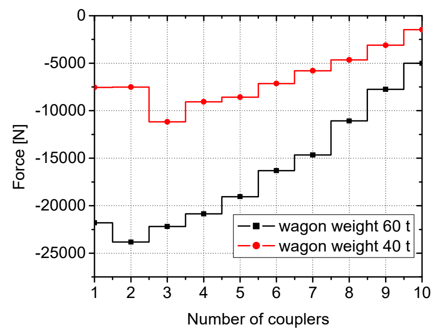

Fig. 5. Distribution of tensile forces to increase the weight of a wagon by 50%.

To observe the influence of the weight on the size and distribution of longitudinal dynamic forces, the study is done on the standard train, changing the weights of all contained wagons. So, a weight increase by 50% leads to marked increase of the compression forces (Fig. 4) approximately by 40% and of tensile forces for about 2.2 times (Fig. 5).

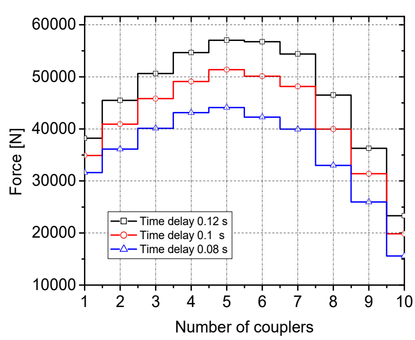

Fig. 6. Distribution of compression forces according to the delay time.

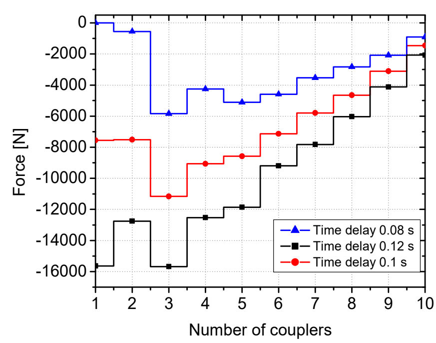

Fig. 7. Distribution of tensile forces according to the delay time.

Changing the delay time regarding the evolution of brake forces directly influences the size of the longitudinal dynamic forces (Fig. 6 and 7). Interestingly, though the values of tensile or compression forces grow depending on the value of *Td*, the distribution of these forces remains practically unchanged. If *Td* reduces, the brake forces between the vehicles of the train equalize faster due to the filling time of the brake cylinder and the forces between the vehicles are small. Increasing the delay time, the time increases until all forces between the vehicles equalize, so that, at a certain time, because of the differences of high brake forces, longitudinal dynamic forces (of compression or tensile) increase.

Conclusions

Longitudinal dynamic forces, that develop in the draw-gear devices when the train brakes, represent the consequence of the successive entry into action of the brakes of each vehicle of the train.

As outlined in the paper, the size of these forces and their distribution are influenced by many parameters, the current study being focused on three of them, namely: the train length, towed weight and the delay time in braking.

Increase or decrease of number of wagons (*Nw*) leads to increases or reductions in the values of the longitudinal forces, but essential changes, as expected, appear to the distribution of these forces referred to the length of the train. Train weight (*Wt*) contributes as long as the vehicles are identical and equal loads only on the values of longitudinal forces.

Variations of the braking delay time (*Td)* parameter change the distribution of tensile forces during stretching, the compression forces having the same distribution, recording only increases or decreases depending on how *Td* changed. Therefore, if a train is made up of vehicles whose lengths vary by 20%, then the forces developed between the vehicles of the train would behave totally differently compared to the train made up of wagons with identical lengths.

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