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ANALYSIS OF WAGON IMPACT

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Abstract

During the wagon impact and during the change of the moving regime (starting, pulling out, and braking) longitudinal forces that significantly influence the tension and deformation of wagon carrying structure appear. In theoretical and experimental analysis there are various attempts to determine values and change of longitudinal forces which disappear in a short time during the wagon impact. In our thesis the certain methodology is suggested, according to which it is possible to determine the quality of values of forces on an experimental basis during the wagon impact.

Keywords: Impact, Wagon, Force

1 Introduction

In the following references [2], [3] there are various attempts to determine longitudinal forces which appear when two wagons collide. However, with an experimental checking [4] it was concluded that obtained formulae don't fully include the influence of cargo movements on the amount of force during collision, the loss of energy during friction which, during collision, happens in different circuits of wagons, the loss of energy during wagon oscillation etc. Additionally, with these formulation the exact force which appears during rough collision of wagons cannot be precisely estimated, that is in the period when buffers become exhausted. In order to estimate the above mentioned influences on the force in buffers during wagon collision, a somewhat complex model is formed.

2 The influence of oscillation energy of wagons on longitudinal force during collision

According to the fact that during collision other forces are smaller than the forces of mutual effect of two wagons, it can be said that the collision is a process in an isolated system where the formula about sustain are dominant (the quantity of movements, energy, etc.). General formulas about sustain are transformed shape of differentiated movement formulae. With their application, the complex process of integration of differentiated formulae is avoided. Let's imagine that the wagon which mass is m_1 moves with the speed v_1 and collides with the wagon which mass is m_2 and moves with speed v_2. During the collision, the centre of masses of adjunct wagons moves with the constant speed and according the formula about sustain of the quality of moving is the following:

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_{cm} = \text{const.} \tag{1}$$

We conclude that the speed of the mass centre v_{cm} during the collision constant and equal to the formula:

$$v_{cm} = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} \tag{2}$$

Generally, the overall kinetic energy of wagon movement during the collision transforms in:

$$\frac{m_1 v_1^2}{2} + \frac{m_2 v_2^2}{2} = \int_{x=0}^{2\Delta\ell} F_o(x)dx + \frac{(m_1 + m_2)v_{cm}^2}{2} + \sum_{i=1}^{n} \int_0^{x_i} b_i \dot{x}_i dx_i + E_{osc} \tag{3}$$

Members on the right part of the formula are:

$\int_{x=0}^{2\Delta\ell} F_o(x)dx$ – absorbed energy of antagonistic springs of both wagons

$\frac{(m_1 + m_2)v_{cm}^2}{2}$ – kinetic energy of the systems during the collision

$\sum_{i=1}^{n} \int_0^{x_i} b_i \dot{x}_i dx_i$ – thermal energy, that is all the forces of fractions of both wagons (thermal energy appears during wagon movements, cargo movement, etc.)

E_{osc} – energy of oscillation of both wagons with cargo,

$x = x_1 - x_2 = 0 \div 2\Delta\ell$ – action when the buffers of both wagons are compacted in case that the buffers of both wagons of the same rigidity, generally: $x = \Delta\ell_1 + \Delta\ell_2$,

$F_o(x)$ – the force in the buffers,
b_i – coefficient of proportionality which characterizes resistance,
$x_i, \dot{x}_i$ – motion and speed of mass

From the formula (3) we can conclude that the overall kinetic energy of the system before the collision transforms in energy of springs in buffers, kinetic energy after collision, lost energy that is wasted on the force of fractions during wagon movement, movement of cargo and oscillation energy which is marked with E_i. It is very hard to determine this energy analytically because it doesn't depend only on speed and the wagon mass but also on other factors. The formula (3) can be written as:

$$\frac{m_1 v_1^2}{2} + \frac{m_2 v_2^2}{2} = \int_{x=0}^{2\Delta\ell} F_o(x)dx + \frac{(m_1 + m_2)v_{cm}^2}{2} + E_i \tag{4}$$

Let's pay attention on energy that is wasted during the collision (E_i). As far as the collision is not fully flexible, a part of the kinetic energy that the wagons possessed before the collision is wasted on deformation and the warming of the body. If we assume that there was no cargo movement during collision, wagon with mass m_1 will have the speed v_1' and the wagon with mass m_2 with speed v_2'. Speeds that are wasted are marked with v_{1i} and v_{2i}, and we will name them lost speeds:

$$v_{1i} = v_1 - v_1'$$

$$v_{2i} = v_2 - v_2^{'} \tag{5}$$

Intensity of the speed of the object during the collision at the end and at the beginning of collision is named by Newton- the coefficient of restitution [3]:

$$k_r = \frac{v_i^{'}}{v_i} \tag{6}$$

$v_i^{'}$ – the speed of mass i after the collision,
v_i – the speed of mass i before the collision

In the previous formula k_r is the coefficient of restitution or the coefficient of collision by which the characteristic such as flexibility of object is introduced. The value of the coefficient of restitution is usually in experimental way differently for various materials. The loss of energy is 0 during the collision of perfectly elastic objects, and in that case je k_r=1. During the collision of ideally plastic objects k_r=0.
During the collision kinetic energy transforms into potential energy of the deformed object. Then, internal elastic forces are usually about to return to the previous shape and then the internal potential energy of the object transforms into kinetic energy. After the restitution only kinetic energy is present which the object had before the collision. The rest of the kinetic energy is wasted on deformation and master the forces of friction, that is on the warming of the body. That's why the speed of the object after the collision is fewer than the speed of the object before the collision. When two wagons collide we have the following formulas:

$$k_r = \frac{v_{cm}\text{-}v_1^{'}}{v_1\text{-}v_{cm}} \quad \text{or} \quad k_r = \frac{v_2^{'} - v_{cm}}{v_{cm} - v_2} \tag{7}$$

According to the theorem about sustain of the quality of movements, the speed of the centres of masses is determined, the formula (2), so if we substitute it for the previous formula, we get:

$$k_r = \frac{m_1(v_1 - v_1^{'}) + m_2(v_2 - v_1^{'})}{m_2(v_1 - v_2)} \quad \text{or} \quad k_r = \frac{m_1(v_2^{'} - v_1) + m_2(v_2^{'} - v_2)}{m_1(v_1 - v_2)} \tag{8}$$

The previous formula helps us to determine the coefficient of restitution for every collision during the initial and final speeds of the observed objects, under the condition that there is no relative moving of cargo over the wagon construction during the collision. By experimental examinations [3] it is proved that the coefficient of restitution depends on elastic features and the shape of the objects that are being collided, and from formula (8) we can conclude that it depends on the masses and the speeds of the objects that are being collided, so the coefficient of restitution is:
k_r= f {elastic features and the shape of objects, mass (m_i) and the speed of the object (v_i) during collision}
In the most frequent case of wagon collision, where the wagons have the same mass (m_1= m_2) and when the speed of the second wagon is zero that is when it is motionless (v_2= 0) and where there is no cargo movement over the wagon construction during the collision, the coefficient of restitution is:

$$k_r = \frac{v_1 - 2v_1^{'}}{v_1} = \frac{2v_2^{'} - v_1}{v_1} \tag{9}$$

As we can see, the coefficient of restitution is very easy to determine if we are familiar with the speed of the first wagon before the collision and the speed of the second wagon after the collision. These speeds are easily determined when we experimentally examine the wagon. But, from this coefficient of restitution we cannot conclude if the cargo was moving or if the examination of wagon was regular. That's why we have additional examining.

2.1 The loss of kinetic energy during two wagons collision

If we mark kinetic energy of two wagons before impact with E_{ko} and with E_k the kinetic energy of the system after the impact then the loss of kinetic energy $\Delta E_k = E_i = E_{osc}$, (during the non-elastic impact of two wagons when tha cargo is motionless) is:

$$E_i = \Delta E_k = E_{ko} - E_k = \frac{1}{2}\left[m_1(v_1^2 - v_1'^2) + m_2(v_2^2 - v_2'^2)\right] \tag{10}$$

When we substitute the previous formula for the formula for the speed of wagons after the impact we get that the loss of kinetic energy during the impact is:

$$E_i = (1-k_r^2)\frac{m_1 m_2 (v_1 - v_2)^2}{2(m_1 + m_2)} \tag{11}$$

It is easy to determine the value of lost energy from the formula (11) and also the maximum value of the force during the wagons impact. The coefficient of restitution can be determined in another way by using experimental results of wagons impact.
During the impact the intensity of the force on the buffers is very easily changed from zero to its maximum value, and then goes back to zero again. If we mark time interval of impact duration with τ, the impact impulse is:

$$I = \int_{t_o}^{t_o+\tau} F_o dt \tag{12}$$

If we mark impulse with I_r and with I_o impulse of the force that equals to the period of shedding we get:

$$I_o = m_1(v_1 - v_{cm}) = m_2(v_{cm} - v_2), \quad I_r = m_1(v_{cm} - v_1') = m_2(v_2' - v_{cm}) \tag{13}$$

So the coefficient of restitution k_r equals to the attitude of those two impulses:

$$k_r = \frac{I_r}{I_o} \tag{14}$$

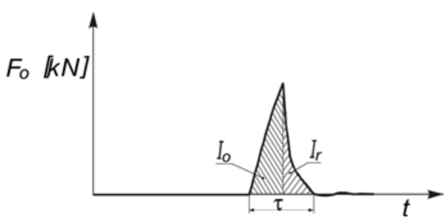

Figure 1 Dependence of the force on the buffers on the time during the impact of wagons

Where: Fo [kN] – force on the buffer
t [ms] – time
τ [ms] – duration of impact of waggons

Impulses I_o and I_r are equal to the adequate areas on the diagram (Fig. 1). In the following head 2.2 you can find the experimental determination of force of impulse in the function of time. This coefficient hasn't properly been examined in the UIC standards and ERRI standards. Namely, in these standards the kind of cargo was described, but not the value which the coefficient of restitution needs to have for a different type of wagons.

If we use inappropriate cargo it is possible to register the forces that are more than 50% fewer that actual values. That's why it is necessary to determine limit values of coefficient of restitution.

2.2 Experimental results

Checking by the experiment was done on three different types of wagons Tadnss-z (Fig.2), Uacns (Fig.3) and Hccrrss (Fig. 4).

On the basis of experimentally measured values of changes of forces in the function of time, the impulses of loading (I_o), the impulses of unloading (I_r) and the coefficient of restitution k_r were measured.

The tested wagon Tadnss-z was loaded with the magnesium are whose moving during the impact is negligible. The value of the coefficient of restitution is within the limits $k_r = 0.91 \div 0.955$.

During the test of the wagon Uacns (which was filled with water), the existing partitions prevented considerable moving of the load during the impact. The values of the coefficient of restitution range within the limits $k_r = 0.90 \div 0.91$, and decline with the increase of speed of impact.

During the test of the Hccrrss wagon for transportation of cars, there was considerable relative moving of parts of the wagon and the load (which consisted of barrels with water) in the longitudinal direction. This resulted in the decrease of the impulse of loading and the decrease of forces registered experimentally. If, as in this case, the impulse of unloading is greater than the impulse of loading ($I_r > I_o$), that is $k_r = 1,2$, it can be concluded that the load moved in the wagon.

These facts, with additional research, can lead to a reliable criterion for the evaluation of validity of the experiment made. Besides, this detail can serve well in designing new similar structures of wagons for purpose of more precise calculation of forces that will appear at the impact.

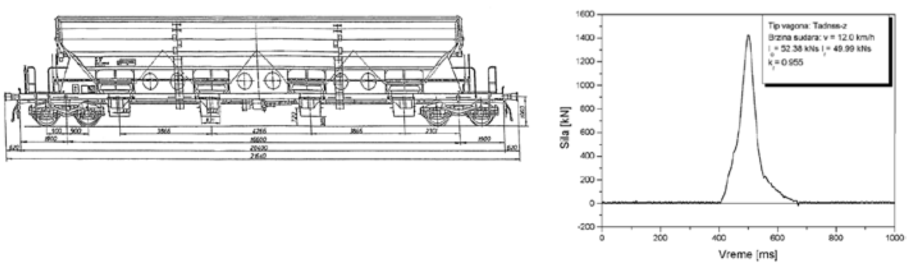

Figure 2 Impact of wagon Tadnss-z

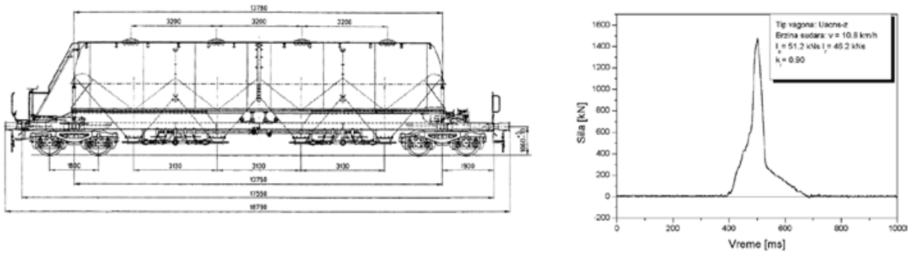

Figure 3 Impact of wagon Uacns-z

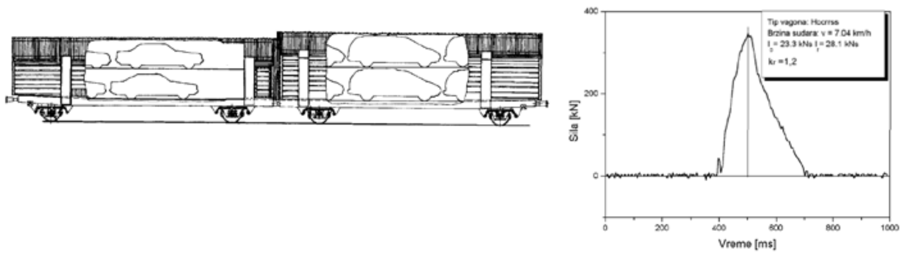

Figure 4 Impact of wagon Hccrrss

3 Conclusion

Further research should be divided in two phases:
In the first phase it is necessary to make comparative tests on impact (using different loads) on several types of wagons and define the experimental methodology of determination of impulses of loading and unloading, that is the coefficient of restitution, determine the minimum necessary frequency of registering and sampling of signals and define all parameters relevant for the evaluation of quality of the experiment made. On the basis of this research, it is possible to give a proposal for addition to the recommendations ERRI B12/RP17 item 3.1. The proposal of addition would contain the obligation of determining the impulse of loading, the impulse of unloading and the coefficient of restitution at the impact of wagons.
The second phase can follow after the adoption of the proposed changes in which the allowed range of the coefficient of restitution would be determined for each type of wagon out of which the results of experimental tests of wagons on impact will be considered irregular.

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