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DISTRIBUTION OF ENERGY IN THE IMPACT OF RAILWAY FREIGHT WAGONS

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Summary

On the basis of laws for conservation of energy this paper examines an energy distribution during the impact of two railway freight wagons. During the wagons impact there are occur a longitudinal forces that significantly influence the tension and deformation of wagon carrying structure. In theoretical and experimental analysis there are various attempts to determine energy distribution and values and changes of longitudinal forces which disappear in a short time during the wagons impact. In the paper the certain methodology for determining the energy distribution is suggested, according to which it is possible to theoretically determine the values of forces which occur in a short time during the wagons impact. Special attention was paid to the influence of energy that is lost by impact. On the basis of such created theoretical model of energy distribution forces on wagons buffers which occur in impact are determined. Such theoretically obtained results are verified experimentally on test polygon for wagons impact, where was wagons Tadnss-z and Uacns-z tested.

Key words: *energy, distribution, impact, railway, freight wagon*

1. INTRODUCTION

Generally, the construction of railway wagon comprises: body, frame, running gear, buffing and draw gear, and various additional instruments and equipment. In the process of impact of wagons complex oscillations that are caused by the characteristics of these sub-assemblies as well as load characteristics and its fixing to the supporting structure of the wagons are created. The problem is compounded by the fact that we are not entirely familiar with the forces that have the influence of wagons in short period of time.

In the following references [2], [3] there are various attempts to determine the energy distribution and longitudinal forces which occur when two wagons impact. 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 the impact, the loss of energy during friction which, during impact, 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 impact of wagons cannot be precisely estimated, that is in the period when buffers become exhausted. In order to properly determine energy distribution and to estimate the above mentioned influences on the force in buffers during the wagons impact, a somewhat complex model is formed.

2. DISTRIBUTION OF ENERGY IN THE WAGONS IMPACT

According to the fact that during impact other forces are smaller than the forces of mutual effect of two wagons, it can be said that the impact 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 this impact, 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:

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

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

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

Generally, the overall kinetic energy of wagon movement during the impact transforms is:

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

Members on the right part of the formula (3) 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 impact

$\sum_{i=1}^{n} \int_0^{x_i} b_i \dot{x}_i dx_i$ - 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 impact transforms in energy of springs in buffers, kinetic energy after impact, 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 impact (E_i). As far as the impact is not fully flexible, a part of the kinetic energy that the wagons possessed before the impact is wasted on deformation and the warming of the body. If we assume that there was no cargo movement during impact, 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:

$$\begin{aligned} v_{1i} &= v_1 - v_1' \\ v_{2i} &= v_2 - v_2' \end{aligned} \tag{5}$$

Intensity of the speed of the object during the impact at the end and at the beginning of impact 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 impact,

v_i - the speed of mass i before the impact

In the previous formula k_r is the coefficient of restitution or the coefficient of impact by which the characteristic such as flexibility of object is introduced. The value of the coefficient of restitution is determined in experimental way, differently for various materials. The loss of energy is 0 during the impact of perfectly elastic objects, and in that case je $k_r=1$. During the impact of ideally plastic objects $k_r=0$.

During the impact 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 impact. 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 impact is fewer than the speed of the object before the impact. When two wagons collide we have the following formulas:

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

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:

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

The previous formula helps us to determine the coefficient of restitution for every impact 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 impact. 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 defined as following function:

$k_r = f$ {elastic features and the shape of objects, mass (m_i) and the speed of the object (v_i) during impact}.

In the most frequent case of wagon impact, 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 impact, the coefficient of restitution is:

$$(9) \quad k_r = \frac{v_1 - 2v_1'}{v_1} = \frac{2v_2' - v_1}{v_1}$$

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 impact and the speed of the second wagon after the impact. 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 impact

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 the cargo is motionless) is:

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

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:

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

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:

$$(12) \qquad I = \int_{t_o}^{t_o+\tau} F_o dt$$

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

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

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

$$k_r = \frac{I_r}{I_o} \quad (14)$$

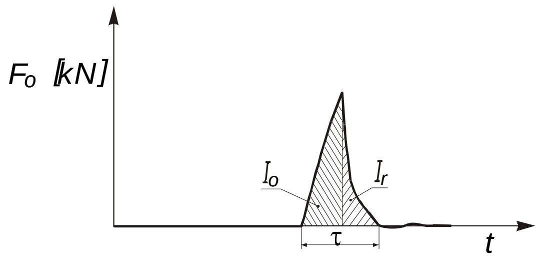

Fig.1. Dependence of the force on the buffers on the time during the impact of wagons

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 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 experimental way was done on test polygon (Fig.2) for wagons impact in Wagon Factory Kraljevo with special measurement equipment (Fig.3).

Fig.2. Test polygon for wagons impact research

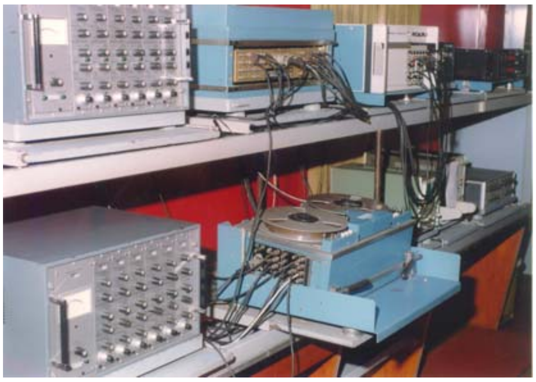

Fig.3. Measurement equipment for wagons impact research

Tests were carried out on two different types of wagons Tadnss-z (Fig.5), and Uacns-z (Fig.7).

Fig.4. Two wagons impact on test polygon

Fig.5. Wagon Tadnss-z

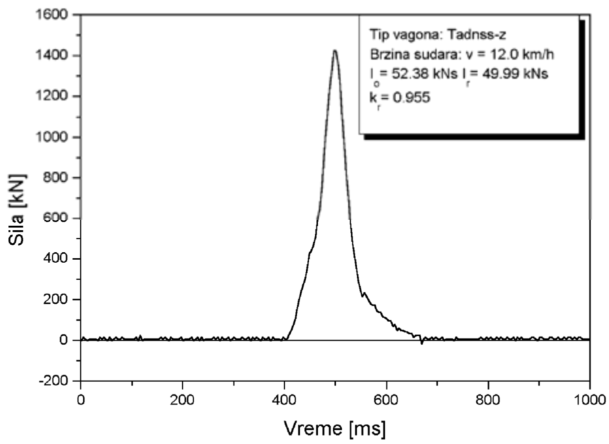

Fig.6. Signal for force on buffer in impact Tadnss-z wagon

Fig.7. Wagon Uacns-z

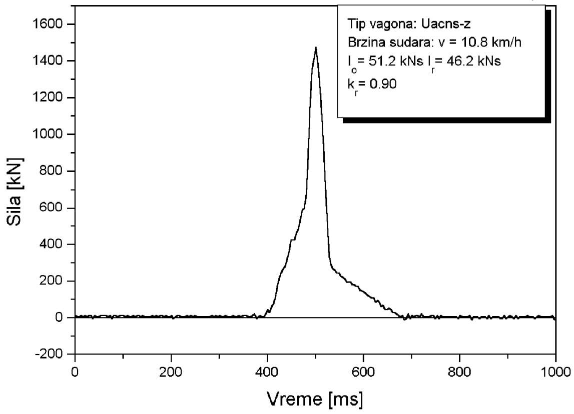

Fig.8. Signal for force on buffer in impact Uacns-z wagon

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 is 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.

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.

In following table there is comparison between theoretical and experimental results for values of forces which occur in impact.

Table 1. Comparision of teoretical and experimental results of forces

Wagons type in impact	Force	Unit	Experimentally	Theoretically
Uah/Ra and Uacns	F^o	[kN]	1280	1311
	F_u^{max}	[kN]	2980	3348
Uah/Ra and Tadnss-z	F^o	[kN]	1502	1562
	F_u^{max}	[kN]	3540	3590

Where:

F^o – Maximum force on buffer until the stroke of buffer springs are exhausted

F_u^{max} – Maximum force in rigid wagons impact

3. CONCLUSION

By comparison of theoretically and experimentally obtained results for forces we conclude that there is a significant correspondance between values. On the basis of that we can conclude that our theoretical model for energy distribution is appropriately composed. For such model it is important to note that coefficient of restitution must be determined by an experimental way.

Further research in this field 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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