On the Reduction of Accelerations Transmitted to Transported Freight for the 4-Axle Platform Car with Mobile Cover

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Abstract: - The shock caused by the collision of railway vehicles determines the transmission of forces and accelerations to the vehicles, which may lead to unwanted consequences. In order to reduce the effects of the shock, vehicles are equipped with shock insulators. The paper presents a unique theoretical approach, completed with an experimental study on the efficiency of long-displacement dampeners in regards to reducing the response amplitude of the mechanical system comprising the two colliding vehicles.

Key-Words: - Shock insulators, long-displacement dampener, stored and dissipated potential deformation energy, accelerations and forces transmitted during shock.

1. Introduction

Due to current tendencies to increase travel velocities and car masses by allowing increasingly larger axle loads, railway equipment shows a series of special problems regarding shock loads that appear during collisions. Collision of railway vehicles occurs in car coupling operations during triage maneuvers and in travel as a consequence of train braking or acceleration. The shock caused by the collision of railway vehicles determines the transmission of considerable forces and accelerations that create accelerations on the transported freight, which may endanger its integrity or that of the affixing or packaging equipment. In order to insulate longitudinal shocks and to protect against them, railway vehicles are equipped with shock insulators:

- Buffers or central coupling dampener;
- Long displacement dampeners, used supplementary in order to protect freight loaded on the cargo platform.

The study is aimed at evidentiating the efficiency of using long displacement dampeners [1] in order to reduce the values of the forces and accelerations transmitted to the transported freight as response functions to the shock caused by collision.

2.The collision process

The general case of the collision of two railway cars is considered. The colliding care, with mass m_1 and velocity v_1, impacts a collided car, of mass m_2 and velocity v_2 ($v_1 > v_2$). The cars are equipped with shock insulators (buffers or central coupling dampeners and a long displacement dampener equipped on he collided car).

Apart from their masses and velocities, the vehicles that partake in the collision can have a series of differences and particularities, such as:

1. The vehicles can be equipped with shock insulators with different characteristics, maximum displacement, force for maximum displacement, dynamically stored and dissipated potential energy, variation form of force vs. Contraction etc.
2. The resistance structures of the carbody, chassis and bogies can be different in regards to the elastic response to the applied forces that appear during collision and thus different values for the stored or dissipated deformation energies.
3. The elastic elements that equip the suspension of the vehicles (springs, dampeners) can have significantly different rigidities and dampening coefficients.
4. The vehicles can be fitted with different equipment, mechanisms or appliances.
5. There can be considerable differences in the quantity, nature and distribution of the freight (passengers, luggage, bulk or packaged freight, containers, auto platforms etc.).

2.1. Definitions and adnotations

In order to describe the stages and significant moments of the collision process it is necessary for a series of definitions and adnotations to be established.

The following definitions and adnotations shall be used further on in the study:

- W_e – potential deformation energy stored by the vehicles’ shock insulators;

- W_a - potential deformation energy dissipated by the vehicles' shock insulators;
- η - the dissipation coefficient for the vehicles' shock insulators, which represents the ratio between the potential deformation energy dissipated and that stored by the shock insulators:

$$\eta = \frac{W_a}{W_e} \tag{1}$$

- W^*_{e1}, W^*_{e2} - potential deformation energy stored by the shock insulators of colliding vehicle 1 and collided vehicle 2, respectively (buffers or central coupling dampener):

$$W^*_{e1} + W^*_{e2} = W_e \tag{2}$$

- W_{e3}; W_{e4} - potential deformation energy stored by buffers 3 and 4, respectively, of colliding car 1;
- W_{e1}; W_{e2} - potential deformation energy stored by buffers 1 and 2, respectively, of collided car 2:

$$W_{e3} + W_{e4} = W^*_{e1} \qquad W_{e1} + W_{e2} = W^*_{e2} \tag{3}$$

- W^*_{a1}, W^*_{a2} - potential deformation energy dissipated by the shock insulators of colliding vehicle 1 and collided vehicle 2, respectively:

$$W^*_{a1} + W^*_{a2} = W_a \tag{4}$$

- W_{a3}, W_{a4} - potential deformation energy dissipated by buffer 3 and 4, respectively, of colliding vehicle 1;
- $W_{a1,}$ W_{a2} - potential deformation energy dissipated by buffer 1 and 2, respectively, of collided vehicle 1;:

$$W_{a3} + W_{a4} = W^*_{a1} \qquad W_{a1} + W_{a2} = W^*_{a2} \tag{5}$$

- η^*_1; η^*_2 - dissipation coefficients for the shock insulators of vehicles 1 and 2, representing the ratio between dissipated and stored potential deformation energy of the buffers or central coupling dampener, which equip the two vehicles:

$$\eta^*_1 = \frac{W^*_{a1}}{W^*_{e1}} \qquad \eta^*_2 = \frac{W^*_{a2}}{W^*_{e2}} \tag{6}$$

- η_3 ; η_4 – dissipation coefficients of buffers 3 and 4 which equip colliding vehicle 1, and which represent the ratio between the dissipated and stored potential deformation energies of buffers 3 and 4, respectively:

$$\eta_3 = \frac{W_{a3}}{W_{e3}} \qquad \eta_4 = \frac{W_{a4}}{W_{e4}} \tag{7}$$

- η_1; η_2 - dissipation coefficients of buffers 1 and 2 which equip collided vehicle 2, and which represent the ratio between the dissipated and stored potential deformation energies of buffers 1 and 2, respectively:

$$\eta_1 = \frac{W_{a1}}{W_{e1}} \qquad \eta_2 = \frac{W_{a2}}{W_{e2}} \tag{8}$$

- W_{es1}; W_{es2} – potential deformation energy stored by the resistance structures of the carbody, chassis and bogies of colliding vehicle 1 and collided vehicle 2, respectively;
- W_{es} – potential deformation energy stored by the resistance structures of the vehicles:

$$W_{es} = W_{es1} + W_{es2} \tag{9}$$

- W_{as1}; W_{as2} - potential deformation energy dissipated by the resistance structures of the carbody, chassis and bogies of colliding vehicle 1 and collided vehicle 2, respectively;
- W_{as} - potential deformation energy dissipated by the resistance structures of the vehicles:

$$W_{as} = W_{as1} + W_{as2} \tag{10}$$

- W_{eB1}; W_{eB2} - potential deformation energy stored by the elastic elements from the suspensions of colliding vehicle 1 and collided vehicle 2, respectively;
- W_{eB} - potential deformation energy stored by the elastic elements from the suspensions of the vehicles:

$$W_{eB} = W_{eB1} + W_{eB2} \tag{11}$$

- W_{aB1}; W_{aB2} - potential deformation energy dissipated by the elastic elements from the suspensions of colliding vehicle 1 and collided vehicle 2, respectively;
- W_{aB} - potential deformation energy dissipated by the elastic elements from the suspensions of the vehicles:

$$W_{aB} = W_{aB1} + W_{aB2} \tag{12}$$

- W_{ev1}; W_{ev2} - potential deformation energy stored by the elastic elements from the suspensions of colliding vehicle 1 and collided vehicle 2, respectively:

$$W_{ev1} = W_{es1} + W_{eB1} \qquad W_{ev2} = W_{es2} + W_{eB2} \tag{13}$$

- W_{ev} - potential deformation energy stored by the elastic elements from the suspensions of the vehicles:

$$W_{ev} = W_{ev1} + W_{ev2} \tag{14}$$

- W_{av1}; W_{av2} - potential deformation energy dissipated by the elastic elements from the suspensions of colliding vehicle 1 and collided vehicle 2, respectively:

$$W_{av1} = W_{as1} + W_{aB1} \qquad W_{av2} = W_{as2} + W_{aB2} \tag{15}$$

- W_{av} - potential deformation energy stored by the elastic elements from the suspensions of the vehicles:

$$W_{av} = W_{av1} + W_{av2} \tag{16}$$

- υ_1, υ_2 – dissipation coefficients of the resistance structure and elastic elements of the suspension of vehicles 1 and 2, respectively, which represent the ratio between dissipated and stored potential deformation energy:

$$\upsilon_1 = \frac{W_{av1}}{W_{ev1}} \qquad \upsilon_2 = \frac{W_{av2}}{W_{ev2}} \tag{17}$$

- υ – dissipation coefficient of the resistance structures and suspension elastic elements of the vehicles:

$$\upsilon = \frac{W_{av}}{W_{ev}} \quad (18)$$

- $W_{eî1}$; $W_{eî2}$ – potential energy stored by mechanisms, equipment, appliances and freight of colliding vehicle 1 and collided vehicle 2, respectively;
- $W_{eî}$ - potential energy stored by mechanisms, equipment, appliances and freight of the vehicles:

$$W_{eî} = W_{eî1} + W_{eî2} \quad (19)$$

- $W_{aî1}$; $W_{aî2}$ - potential energy dissipated by mechanisms, equipment, appliances and freight of colliding vehicle 1 and collided vehicle 2, respectively;
- $W_{aî}$ - potential energy dissipated by mechanisms, equipment, appliances and freight of the vehicles:

$$W_{aî} = W_{aî1} = W_{aî2} \quad (20)$$

- τ_1, τ_2 – dissipation coefficients of mechanisms, equipment, appliances and freight of colliding vehicle 1 and collided vehicle 2, respectively, which represent the ratio between dissipated and stored potential energy:

$$\tau_1 = \frac{W_{aî1}}{W_{eî1}} \qquad \tau_2 = \frac{W_{aî2}}{W_{eî2}} \quad (21)$$

- τ - dissipation coefficient of mechanisms, equipment, appliances and freight:

$$\tau = \frac{W_{aî}}{W_{eî}} \quad (22)$$

- E_{c1}; E_{c2} - kinetic energy of colliding vehicle 1 and collided vehicle 2, respectively, at time t = 0;
- E_c - kinetic energy of the vehicles at t = 0;

$$E_c = E_{c1} + E_{c2} \quad (23)$$

- E_{12} - kinetic energy of colliding vehicle 1 and collided vehicle 2, respectively, at time $t = t_{12}$, when $v_1(t) = v_2(t)$ and the process of transformation of vehicles kinetic energy into potential deformation energy is ended;
- E^*_{c1}; E^*_{c2} - kinetic energy of colliding vehicle 1 and collided vehicle 2, respectively, at time $t = t^*_{12}$, from which the momentary velocities of the vehicles remain constant until the time t_2 and equal to v^*_1 and v^*_2 respectively;
- E^*_c - kinetic energy of the vehicles on the time interval ($t^*_{12} - t_2$), including moment t_2:

$$E^*_c = E^*_{c1} + E^*_{c2} \quad (24)$$

- E_{p1}; E_{p2} – stored potential energy for the colliding vehicle 1 and collided vehicle 2, respectively:

$$E_{p1} = W_{e1} + W_{ev1} + W_{eî1} \quad (25)$$
$$E_{p2} = W_{e2} + W_{ev2} + W_{eî2}$$

- E_p - potential energy of the vehicles:

$$E_p = E_{p1} + E_{p2} = W_e + W_{ev} + W_{eî} \quad (26)$$

- E_{a1}; E_{a2} - dissipated potential energy for the colliding vehicle 1 and collided vehicle 2, respectively, at time $t = t_2$:

$$E_{a1} = W_{a1} + W_{av1} + W_{aî1} \quad (27)$$
$$E_{a2} = W_{a2} + W_{av2} + W_{aî2}$$

- E_a - dissipated potential energy during the collision process at time $t = t_2$:

$$E_a = E_{a1} + E_{a2} = W_a + W_{av} + W_{aî} \quad (28)$$

In the collision process, part of the kinetic energy of the vehicles is transformed into stored potential deformation energy E_p, which is at a maximum at time t_{12} when the vehicles travel with the same velocity v_{12}. The expression of the stored potential deformation energy is:

$$E_p = \frac{m_1 m_2}{m_1 + m_2} \frac{(v_1 - v_2)^2}{2} = \frac{m_1 m_2}{m_1 + m_2} \frac{v^2}{2} \quad (29)$$

2.2. Experimental application

In the case of the collision of two vehicles with masses m_1=80000kg and m_2=90000kg, with collision velocities of de v_1=2,897m/s and v_2=0, respectively, equipped with category A buffers, according to UIC 526-1, specifically with W_{emax}=30kJ, we have represented the time evolution of the kinematic (figure 1) and energetic parameters (figure 2).

The considered kinematic parameters of the colliding and collided cars are:

- distance traveled $x_1(t)$ and $x_2(t)$;
- collision velocities $v_1(t)$ and $v_2(t)$;
- accelerations transmitted to the vehicles $a_1(t)$ and $a_2(t)$.

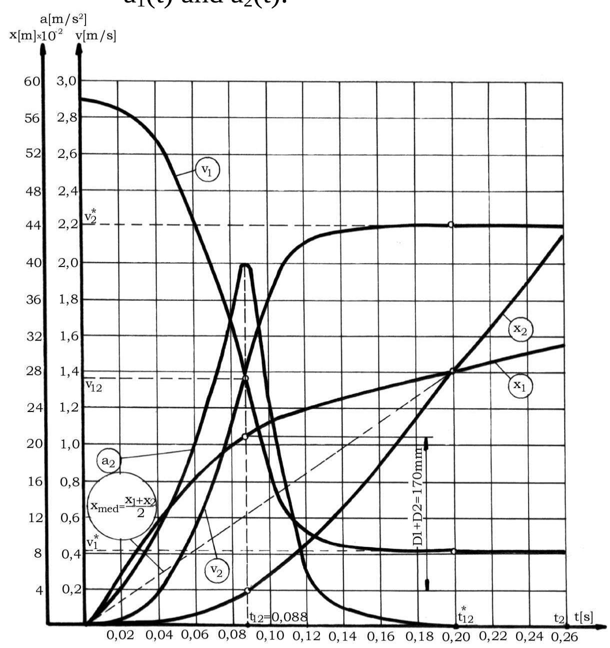

Fig.1 Time evolution of acceleration $a_2(t)$, of collided car 2, determined experimentally and derived parameters $v_1(t)$, $v_2(t)$, $x_1(t)$ şi $x_2(t)$, for $A \rightarrow A$ collision.

For the presented collision trial, the time evolutions of the following parameters were determined experimentally, using adequate measurement, recording and analysis apparata:

- $F_1(t)$, $F_2(t)$ – forces transmitted to the cars through the buffers;
- $D_1(t)$, $D_2(t)$ – contractions of buffers 1 and 2 of collided car 2;
- $a_2(t)$ – acceleration of collided car 2;
- v_1 – velocity of colliding car 1 at time $t = t_1 = 0$ of the beginning of the collision process.

Given the experimental diagram $a_2 = f(t)$, through integration we have obtained the time evolution of the velocity of the collided car $v_2(t)$, throughtout the collision process (0 - t_2):

$$v_2(t) = \int a_2(t)dt \tag{30}$$

Using the same method of integration, the distance traveled by the collided car $x_2(t)$ was obtained for the collision process (0 - t_2):

$$x_2(t) = \int v_2(t)dt \tag{31}$$

Also through integration, the time evolution of the velocity of the colliding car was obtained $v_1(t)$:

$$v_1(t) = -\int \frac{m_2}{m_1} a_2(t)dt \tag{32}$$

And the distance traveled $x_1(t)$:

$$x_1(t) = \int v_1(t)dt \tag{33}$$

Thus, the time evolutions of the resulting kinetic parameters, $v_2(t)$, $x_2(t)$, $v_1(t)$, $x_1(t)$, were represented using adequate computer software.

The following observations are made:

1. The intersection of curves $v_1(t)$ and $v_2(t)$ occurs in a significant point of coordinates (t_{12} , v_{12}), which marks the moment when the vehicles travel at the same velocity v_{12}. A rigurous accordance is observed between the value of v_{12}, computed with initial parameters m_1, v_1, m_2, v_2 and the formula

$$v_{12} = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} \tag{34}$$

and the experimentally obtained value.

2. Acceleration $a_2(t)$ reaches a maximum at time t_{12} and becomes zero at t_{12}^*.

3. At time t_{12}, the difference between distances traveled by the cars represents the maximum contraction of the cars' buffers, highlighted on the diagrams:

$$x_1(t_{12}) - x_2(t_{12}) = D \tag{35}$$

By experimentally measuring the contractions of the buffers from the collided car, an average value was determined $D_{2\ med} = (D_1+D_2)/2=85mm$. Considering the fact that the cars were equipped, in both cases, with the same type of buffers, a very good accordance is observed between the experimentally obtained values from the diagrams and the directly measured values.

4. The moment the vehicles reach the final velocities v_1^* and v_2^*, for the collision process, is $t = t_{12}^*$ and does not correspond to the moment t_2 at which the contractions of the shock insulators cancel out and which marks the end of the collision. The time interval $(t_{12}^* - t_2)$ is noted, during which the contact between the buffer plates is maintained since the increase in the distance between the vehicles, caused by their velocities, is compensated by the expansion of the buffers. The complete expansion of the buffers occurs at time t_2, moment considered as the end of the collision process.

From the experimental determination of the input parameter v_1, and output parameters $F_1(t)$, $F_2(t)$, $D_1(t)$, $D_2(t)$, $a_2(t)$, from the system formed by the two vehicles during the shock caused by collision, the following measures were determined:

1. $E_{c1}(t)$, $E_{c2}(t)$, $E_c(t)$ – kinetic energy of colliding vehicle 1 and collided vehicle 2, respectively, and their sum, using the established velocity functions $v_1(t)$ and $v_2(t)$ and represented in the diagrams in figure 2.

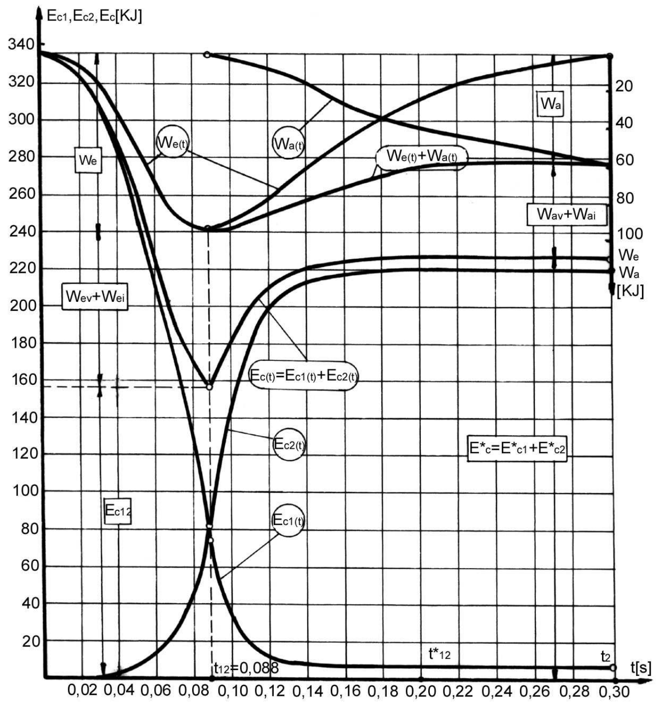

Fig.2. Time evolution of the mentioned energy parameters, on the time interval (0-t_2) of the collision process, for the A → A collision

2. With the experimental determinations of $F_1(t)$, $F_2(t)$, $D_1(t)$, $D_2(t)$, the diagrams $F_1 = f(D_1)$ and $F_2 = f(D_2)$ were established for buffers 1 and 2, respectively, for the collided car 2.

Hence, we could determine:

$$W_{e1} = \int_0^{D_1} F_1(D_1)dD_1$$
$$W_{a1} = \int F_1(D_1)dD_1 \quad (36)$$
$$W_{e2} = \int_0^{D_2} F_2(D_2)dD_2$$
$$W_{a2} = \int F_2(D_2)dD_2$$

as well as:

$$W_{emed} = \frac{W_{e1} + W_{e2}}{2}$$
$$W_{amed} = \frac{W_{a1} + W_{a2}}{2} \quad (37)$$

Figure 3 shows the diagrams for the variation with average contraction $D_{med} = (D_1 + D_2) / 2$ of the average stored potential deformation energy W_{emed}, average dissipated potential deformation energy W_{amed} and their sum for the process of the A $\rightarrow$ A collision.

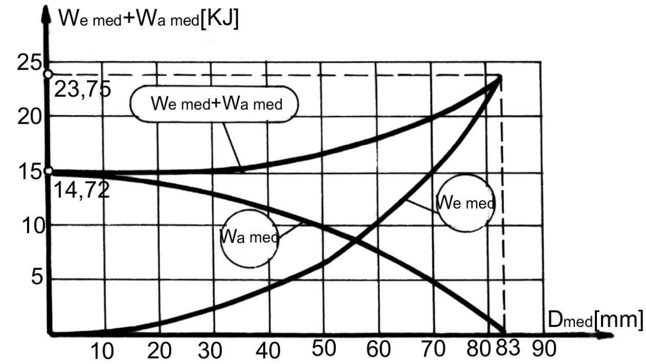

Fig.3 Representation of the average stored potential energy W_{emed} [KJ], average dissipated potential energy W_{amed} [KJ] and their sum W_{emed} + W_{amed} as a function of the contraction D_{med} [mm] for a category A buffer

3. Since the buffers equipping the vehicles were of the same type, category A, the functions $W_e(t)$, $W_a(t)$, $[W_e(t) + W_a(t)]$ were determined as follows:

$$W_e(t) = 4W_{emed}(t)$$
$$W_a(t) = 4W_{amed}(t) \quad (38)$$

by using the values shown in the diagrams from figure 3.

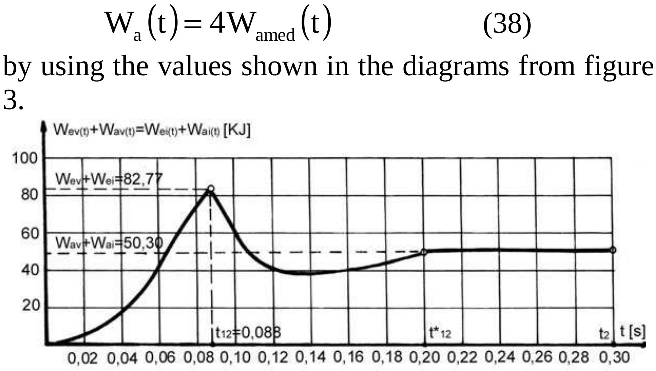

Fig.4. Time evolution of the mentioned energy parameters, on the interval (0-t_2) of the A $\rightarrow$ A collision process

Figure 4 shows the time evolutions of the parameters determined for the considered A $\rightarrow$ A collision cases, on the time interval (0 - t_2):

- $E_{c1}(t)$, $E_{c2}(t)$, $E_c(t) = E_{c1}(t) + E_{c2}(t)$, kinetic energy of the colliding vehicle 1, kinetic energy of the collided vehicle 2, and kinetic energy of the mechanical system formed by the two cars;
- $W_e(t)$, $W_a(t)$, $[W_e(t) + W_a(t)]$, stored potential deformation energy, dissipated potential deformation energy for the 4 buffers of the considered mechanical system, as well as the sum of the two energies.

For the representation of the functions $W_e(t)$, $W_a(t)$, and $W_e(t) + W_a(t)$, the X-axis was chosen at the level of maximum kinetic energy:

$$E_{c\max} = E_{c1} + E_{c2} = \frac{m_1 v_1^2}{2} \quad (39)$$

and the Y-axis for these functions has the direction reversed. Such a representation was used in order to highlight the energy balance at each moment of the collision process (0 - t_2) and to determine the time evolution of the parameter constituting the difference:

$$E_c(t) - (W_e(t) + W_a(t)) = W_{ev}(t) + W_{e\hat{i}}(t) + W_{av}(t) + W_{a\hat{i}}(t) \quad (40)$$

which represents the value of the stored and dissipated potential energies of the cars and their freight. Thus determined, this parameter was represented as a function of time in figure 4, for the considered A $\rightarrow$ A collision case.

2.3. The collision process

From the study of the presented diagrams, the following observations are made on the collision process:

1. At the start of the collision, $t = t_1 = 0$, the kinetic energy of the mechanical system formed by the vehicles $E_c(t)$ is maximum.

2. On the interval (0 - t_{12}) the kinetic energy of the colliding vehicle $E_{c1}(t)$ decreases, and that of the collided vehicle $E_{c2}(t)$ increases. Their sum, $E_c(t)$, considerably decreases on the account of transformation into potential energy stored by the buffers W_e, cars W_{ev} and freight $W_{e\hat{i}}$.

3. At time t_{12}, the kinetic energy of the cars is minimum:

$$E_c(t_{12}) = E_{c12} = \frac{(m_1 + m_2)v_{12}^2}{2} \quad (41)$$

while the stored potential energy is maximum:

$$E_p = W_e + W_{ev} + W_{e\hat{i}} \quad (42)$$

4. On the interval $(t_{12} - t_{12}^*)$ the process of transforming stored potential deformation energy into

kinetic energy starts, as well as that of of dissipating potential energy.

5. At time t_{12}^* the kinetic energy of the cars is equal to that for the moment t_2:

$$E_c(t_{12}) = E_c(t_2) - E_c^* = E_{c1}^* + E_{c2}^* \qquad (43)$$

Furthermore, the sum of the stored and dissipated potential energy is equal to the potential energy dissipated at time t_2:

$$\left(W_e(t_{12}^*) + W_{ev}(t_{12}^*) + W_{e\hat{i}}(t_{12}^*)\right) + \left(W_a(t_{12}^*) + W_{av}(t_{12}^*) + W_{a\hat{i}}(t_{12}^*)\right)$$
$$= E_c - E_c^*(t_{12}^*) = E_c - E_c^* = W_a + W_{av} + W_{a\hat{i}} \qquad (44)$$

6. On the interval $(t_{12}^* - t_2)$ the kinetic energy of the cars E_c^* remains constant under the conditions of the compensation of the drop in stored potential deformation energy by release of dissipated potential energy from the system.

7. At time t_2 the energy balance is:

$$E_c = \frac{m_1 v_1^*}{2} = E_c^* + \left(W_a + W_{av} + W_{a\hat{i}}\right) \qquad (45)$$

3. The shock caused by collision on the 4-axle platform car with mobile cover, equipped with long-displacement dampener

3.1.Theoretical study

The mechanical model studied further on represents the system of the vehicles and shock insulators that partake in the collision process, and it is represented in figure 5.

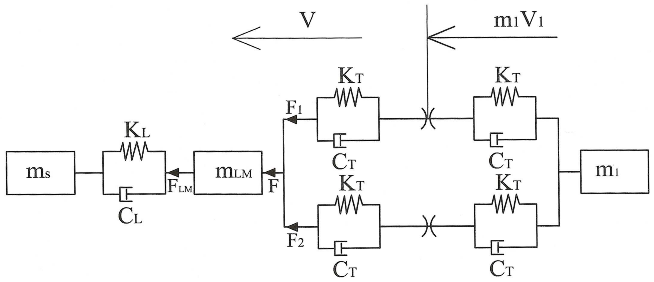

Fig. 5 (K_L, K_T – long displacement dampener and buffer rigidities; C_L, C_T – long diplacement dampener and buffer dampening; m_S – mass of the useful load bearing chassis; m_{LM} – mass of mobile beam; $m_2=m_s+m_{LM}$)

Considering the conservation of momentum and energy, the following moments and intervals are noted for the collision process:

1. At time $t = t_1 = 0$, which represents the start of the collision, the vehicles have velocities v_1, and v_2, such that:

$$E_c = E_{c1} + E_{c2} = \frac{m_1 v_1^2}{2} + \frac{m_2 v_2^2}{2} \qquad (46)$$

where:

- E_c total kinetic energy;
- E_{c1} kinetic energy of colliding car;
- E_{c2} kinetic energy of collided car.

2. On the time interval $t = 0$ up to $t = t_{12}$ a part of the kinetic energy of the vehicles $E_c(t)$ is transformed into potential deformation energy $E_p(t)$ as follows:

- in the shock insulators $W_e(t)$;
- in the resistance structures of the vehicles $W_{es}(t)$;
- in the elastic elements of the vehicles' suspensions, in equipment and appliances $W_{eB}(t)$;
- in the vehicle freight $W_{e\hat{i}}(t)$.

The potential deformation energy stored by the vehicles is defined as:

$$W_{ev}(t) = W_{es}(t) + W_{eB}(t) \qquad (47)$$

Thus:

$$\frac{m_1 v_1^2}{2} + \frac{m_2 v_2^2}{2} = \frac{m_1 v_1^2(t)}{2} + \frac{m_2 v_2^2(t)}{2} + E_p(t) \qquad (48)$$

$$E_p(t) = W_e(t) + W_{ev}(t) + W_{e\hat{i}}(t) \qquad (49)$$

$$W_e(t) = W_{eA}(t) + W_{eTA}(t) \qquad (50)$$

where:

- W_{eA} is the deformation energy stored by the long displacement dampener;
- W_{eTA} is the deformation energy stored by the shock insulators (buffers or central coupling dampeners).

3. At time $t = t_{12}$ the two vehicles have equal velocities $v_1(t) = v_2(t) = v_{12}$, the process of transforming kinetic energy into potential deformation energy ceases, E_p reaches a maximum. Hence:

$$\frac{m_1 v_1^2}{2} + \frac{m_2 v_2^2}{2} = (m_1 + m_2)\frac{v_{12}^2}{2} + E_p(t_{12}) \qquad (51)$$

4. On the time interval $(t_{12} - t_{12}^*)$ the kinetic energy of the vehicles has a tendency to increase due to the transformation of a part of the stored potential deformation energy $E_p(t)$ into kinetic energy. The other part is or was dissipated from the mechanical system $E_a(t)$.

Conservation of energy between t=0 and a moment on the interval $(t_{12} - t_{12}^*)$ is:

$$\frac{m_1 v_1^2}{2} + \frac{m_2 v_2^2}{2} = \frac{m_1 v_1^2(t)}{2} + \frac{m_2 v_2^2(t)}{2} + E_p(t) + \qquad (52)$$
$$+ E_a(t) = E_{cv}(t) + E_{ca}(t) + E_p(t) + E_a(t)$$

where:

- $E_{cv}(t)$ kinetic energy proper to the vehicles;
- $E_{ca}(t)$ kinetic energy returned to the system by transforming a part of the potential deformation energy of the mechanical system comprising the two vehicles;
- $E_p(t)$ potential deformation energy still in existence in the considered mechanical system;
- $E_a(t)$ stored and dissipated potential deformation energy.

$Ea(t) = Wa(t) + W_{av}(t) + Wa_{î}(t)$ (53)
$W_{av}(t) = W_{as}(t) + W_{aB}(t)$ (54)
$W_a(t) = W_{aA}(t) + W_{aTA}(t)$ (55)

5. The time t_{12}^* is the moment when the force transmitted to the vehicles F(t) = 0 and consequently the process of energy transformation has ended. The collision induced shock process ends at time t_2 when the shock insulators have the same deformation state as at time t = 0. At this moment t = t_{12}^* (buffers still have a remaining deformation), the velocities of the vehicles are v_1^* and v_2^*.

The sum between the stored potential deformation energy still existing at this time $E_p(t_{12}^*)$ and the potential deformation energy dissipated up to this time $E_a(t_{12}^*)$ is equal to the potential deformation energy dissipated in the collision process E_a:

$$E_p(t_{12}^*) + E_a(t_{12}^*) = E_a(t_2) = E_a \quad (56)$$

6. The time t = t_2 marks the end of the collision process. Hence:

$$\frac{m_1 v_1^2}{2} + \frac{m_2 v_2^2}{2} = \frac{m_1 v_1^{*2}}{2} + \frac{m_2 v_2^{*2}}{2} + E_a \quad (57)$$

or:

$$E_c = E_{c1} + E_{c2} = E_{c1}^* + E_{c2}^* + E_a = E_c(t_2) + E_a \quad (58)$$

and

$$E_c = E_{cv}(t_2) + E_{ca}(t_2) + E_a = E_{cv}(t_2) + E_p \quad (59)$$

3.2.The energy characteristics of the shock caused by collision

Using shock insulators with superior dynamic characteristics has the following consequences:

- spectacular decrease of the maximum forces transmitted to the vehicles, with direct consequences on the protection of resistance structures by decrease of specific deformations and stresses caused by the shock during collision;

- decrease of the level of accelerations transmitted to the vehicles down to values that ensure a necessary protection of freight and equipment, as well as an enhanced passenger comfort.

The energy factors are defined as: 2β = f(v), coefficient which describes the collision process for railway vehicles [1]; 2λ = f(v); 2δ=f(v); 2χ=f(v) which pertain to the stored potential deformation energy E_p. Thus:

$$2\beta = \frac{W_e}{E_p};\ 2\lambda = \frac{W_{es}}{E_p}; \quad (60)$$

$$2\delta = \frac{W_{eB}}{E_p};\ 2\chi = \frac{W_{eî}}{E_p}$$

It is obvious that:

$$2\beta + 2\lambda + 2\delta + 2\chi = \frac{W_e + W_{es} + W_{eB} + W_{eî}}{E_p} = 1 \quad (61)$$

Further on, the dissipation energy coefficients are defined, which characterize the process of eliminating stored potential deformation energy during the course of the shock caused by collision. Hence:

- the dissipation energy coefficient of the mechanical system;

$$2\alpha = \frac{E_a}{E_p} \quad (62)$$

- the dissipation energy coefficient of the shock insulators;

$$\eta_a = \frac{W_a}{W_e} = \frac{W_a}{2\beta E_p} \quad (63)$$

- the dissipation energy coefficient of the vehicles and their freight.

$$\eta_{aSBÎ} = \frac{W_{aS} + W_{aB} + W_{aî}}{(1-2\beta)E_p} = \frac{E_a - W_a}{(1-2\beta)E_p} \quad (64)$$

The relationship between the fundamental storage and dissipation energy coefficients, which characterize the collision process, is obtained:

$$2\alpha = 2\beta\eta_a + (1-2\beta)\eta_{aSBÎ} \quad (65)$$

It is extremely important that the bearing structures, the elastic elements of the suspension, the functional equipment as well as the nature and quantity of the freight are determined by other defining criteria than that of the response to the longitudinal shock caused by collision. Thus, the only practical possibility to diminish the effects of the shock is to increase the potential deformation energy stored by the shock insulators. Hence it can be explained why it can be considered that the 2β=f(v) coefficient represents the specific energy coefficient that characterizes the shock phenomenon for railway vehicles.

During the collision of two railway vehicles with relative velocity v, the potential energy that pertains to the vehicles (2λ+2δ+2χ)E_p is the result of the work done by the forces transmitted in the process of the collision.

In order to decrease the level of the forces transmitted during the collision, two solutions are adequate:

1. modifying the elements of the vehicles in order to increase their flexibility;

2. increasing the storage capacity and the 2β coefficient, through the use of shock insulators with superior dynamic characteristics.

The second solution is generally adopted by vehicle producers both in the design phase and, most commonly, in the prototype or existing vehicle phase.

3.3. Experimental research

The collision tests were conducted with the platform care on 4 axles with mobile cover, equipped with category A buffers and OLEO INTERNAŢIONAL long displacement dampener (figure 6).

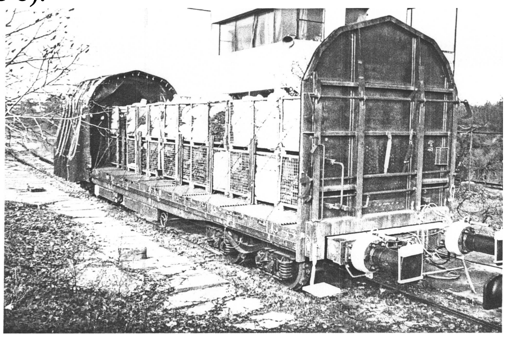

Fig. 6

Figure 7 shows the affixing method for the long displacement dampener (1), interposed between the mobile beam and the bearing platfom (load bearing chassis), as well as the affixing method for the force transductor (2) used to determine the force transmitted through the long displacement dampener.

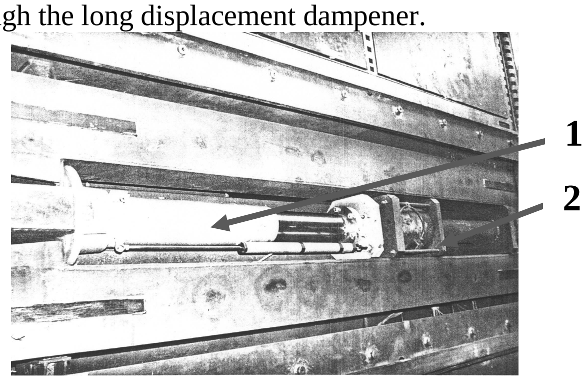

Fig. 7

The collided car was loaded with pellets and small material in two variants:

a) up to a mass of 56.960 kg with half the useful load;

b) up to a total mass of 90.000 kg.

The colliding car was a gondola-type car loaded with sand up to a mass of 80t, equipped with category A buffers, according to UIC 526-1.

During the testing the following parameters were determined as response functions of the tested collided car:

- F1; F2 [kN] – forces transmitted through the car's bumpers;
- D1; D2 [mm] – contraction of the buffers;
- F_{LM} [kN] – force transmitted by the mobile beam to the long displacement dampener;
- D_{LM} [mm] – contraction of the long displacement dampener;
- a_S [g] – acceleration on the bearing chassis on which the transported freight is affixed;
- a_{LM} [g] – acceleration of the mobile beam.

The colliding car was launched from an inclined plane and collided, at various velocities, the tested car located on a level, straight track. The experimental results for the conducted collisions are shown in Table 1.

Table 1

Measured parameters	Car with mass 56.960 kg (variana a)						
	Velocity [km/h]						
	7,1	8,12	8,95	10,16	10,84	11,61	12,0
F [kN]	224	271	309	376	417	453	476
F_{LM} [kN]	219	282	347	427	472	534	565
D_1 [mm]	32	38	41	48	51	56	59
D_2 [mm]	27	32	35	41	46	49	53
D_{LM} [mm]	289	312	317	329	336	340	340
a_s [m/s^2]	0,67	0,86	0,92	1,44	1,63	1,67	1,74
a_{LM} [m/s^2]	4,13	4,54	5,00	6,10	6,48	6,68	6,82
Measured parameters	Car with mass 56.960 kg (variana a)						
	Velocity [km/h]						
	8,29	8,95	10,22	10,87	11,68		
F [kN]	294	326	393	418	470		
F_{LM} [kN]	346	390	486	499	570		
D_1 [mm]	35	38	46	50	55		
D_2 [mm]	27	31	37	44	49		
D_{LM} [mm]	337	340	347	350	350		
a_s [m/s^2]	0,65	0,7	0,95	1,05	1,22		
a_{LM} [m/s^2]	5,09	5,3	6,13	6,44	6,95		

From the analysis of the experimental results for collision variant "b" (V=11,68 km/h), it is determined that the duration of the collision process is 0,75 s. From the integration of the curve of the acceleration on the bearing chassis as a function of time we have determined the the evolution of velocity as a function of time during the collision process, figure 8. The time evolution of the acceleration of the bearing chassis a_S is shown in figure 9.

On the figure, the velocities at times t = 0, beginning of the collision process, and at time t_2 = 0,75s end of the collision process, are shown. Also, the moment $t_{1,2}$=0,27s is to be noted, moment at which the process of transformation of the kinetic energies of the masses that partake in the shock into stored potential deformation energy has concluded, and the masses of the vehicles travel at the same velocity.

From the energy balance for case "b" for the collision of the car with mass 90000kg at collision velocity v = 11,68km/h the following significant experimentally determined values are obtained: 2β = 0,747; 2α = 0,719; η_a= 0,843; $\eta_{aSBî}$= 0,35 (with the observation that $W_{aî}$ has the maximum share).

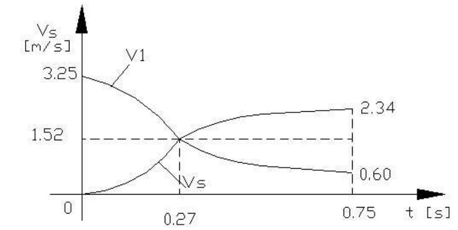

Fig. 8

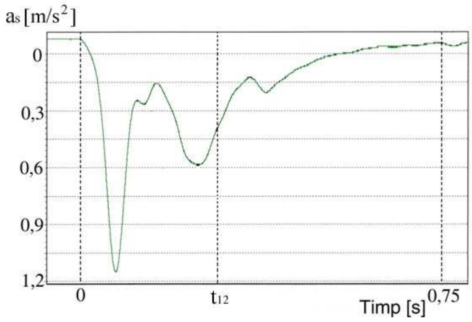

Fig. 9

Figures 12, 13 and 16 show the characteristic diagrams of buffer 1, buffer 2 and long displacement dampener, for situation b, collision at 11,68km/h.

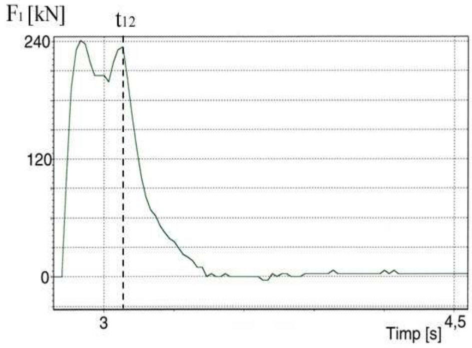

Fig. 10

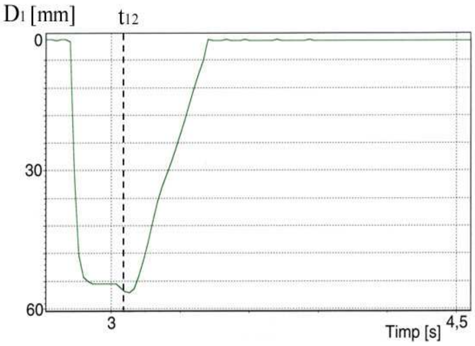

Fig. 11

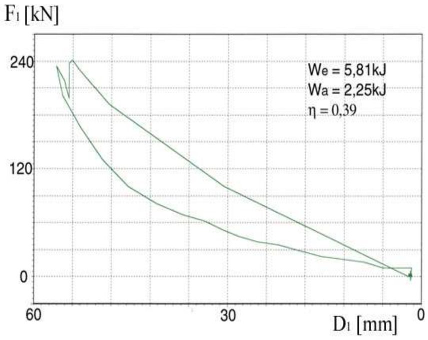

Fig. 12

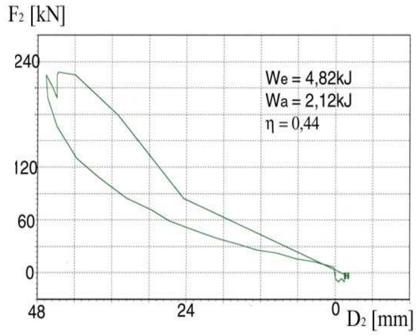

Fig. 13

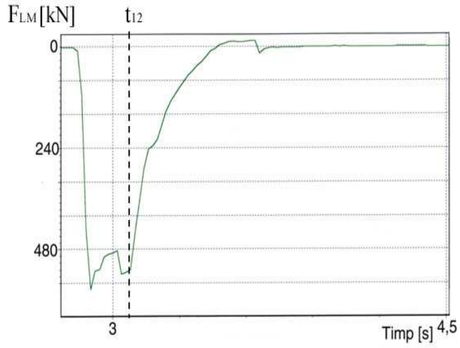

Fig. 14

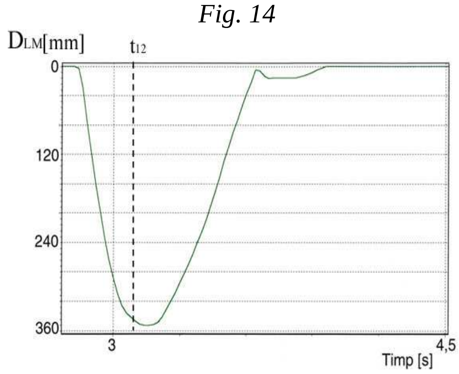

Fig. 15

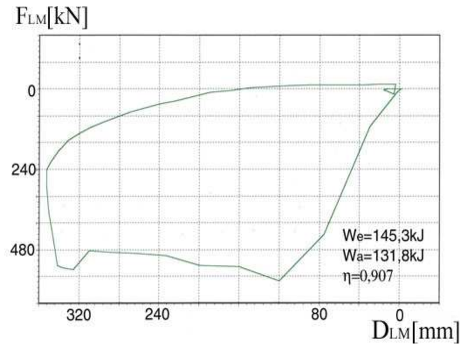

Fig. 16

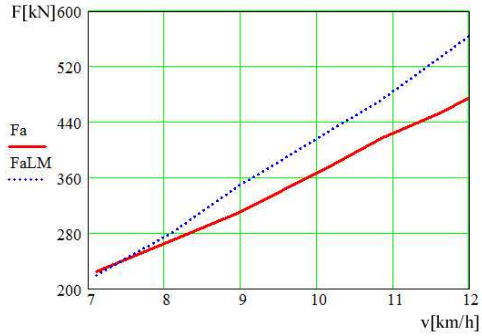

Fig. 17

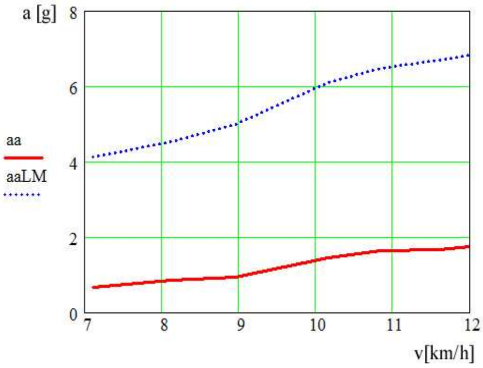

Fig. 18

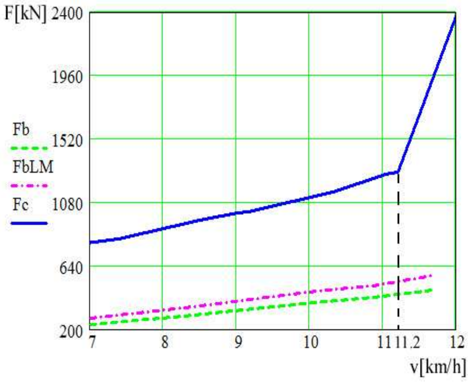

Fig. 19

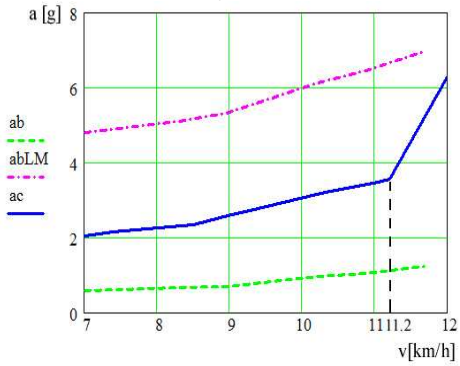

Fig. 20

Figures 10 and 14 and figures 11 and 15 show the variations with velocity of transmitted force and shock insulator contractions, respectively.

Figures 17 and 18 show the variations with velocity of the transmitted force and the acceleration of the loaded bearing chassis, for situation a.

Figures 19 and 20 show the variations with velocity of the transmitted force and the acceleration for situation b, together with the variations of the transmitted force F_c and acceleration a_c for the collision of two vehicles (m_1=80t, m_2=90t) without a long displacement dampener. The collision velocity of 11,2Km/h is highlighted on the diagram, velocity at which the shock insulators reach the maximum displacement.

4. Conclusions

1. With the increase of velocity and mass of transported freight, differences appear between the values of the forces F_a,F_b and F_{aLM}, F_{bLM} as well as between the values of the accelerations a_{aS}, a_{bS} and a_{aLM}, a_{bLM} due to the series insertion of the long displacement dampener into the mechanical system, which leads to an increase in the storage capacity for potential deformation energy.

2. The force transmitted to the useful load bearing chassis and its acceleration decrease spectacularly (by approximately 60% - 85%) in comparison to a similar collision, during which the collided car is not equipped with a long displacement dampener.

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