INDUCING COLLISION OF VEHICLES WITH THE INCOMPATIBLE ENERGY CONSUMPTION OF BODYWORKS IN DEFORMATION ZONES

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Abstract

In the field of automotive safety, both geometrical and energy compatibility [5] of bodyworks is one of the issues. While inducing collision of vehicles with different sizes and mass, breakdowns of "smaller" vehicle may occur. For this reason, correctly designed automobiles have elements put at the same height, which are consuming energy while confronting, both bumpers, and elements of the zone of the controlled crumple. On account of limited dimensions, vehicles cannot have an effective zone of the controlled crumple from the side. At hitting with the front part of the vehicle in the side of another vehicle, most often deep deformations of the structure of the bodywork are reached and as a result of it - serious injury of passengers which were in the vehicle.

In the article reconstruction of the road event was shown, consisting in hitting with the front part of the vehicle Volkswagen Golf into the side of the vehicle Mercedes. As a result of the accident the driver of one of the vehicles died, however the driver and the passenger of the second vehicle, despite of the high speed of the vehicle, didn't sustain injuries. The analyzed case is the example of the collision of vehicles with incompatible energy structures in the place of their contact. Repeatedly, the higher stiffness of the front part of the vehicle and the zone of the controlled crumple assured safety for its passengers, with the cost of the safety of the driver of the second vehicle. During the reconstruction of the event, the method of calculation leaning against the Burg model, modified on account of the movement of one of the vehicles all over the road surface with variable mechanical properties, was applied.

Keywords: *road transport, road accident reconstruction, deformation zone, geometrical and energy compatibility*

1. Introduction

Velocity is the basic parameter which is deciding on the effects of the road event. Changes of the structure of vehicles in the passive safety aim at providing surviving the driver and the passengers of the vehicle for the possibility at confronting with the obstacle or other vehicle, but certain border exists, which cannot be crossed. At the certain velocity it isn't possible to ensure conditions of the experience, even in the vehicle regarded safe.

Velocity in itself isn't deciding on effects of the event, the value of the acceleration which is calling inertial forces working on the human body, is significant and more precisely - the peak of the delay and the time of the exhibition [5]. Of course, between the velocity of the collision and the values of decelerations a relation exists, but also the other factors have the influence on the value of inertial forces.

Every automobile before certifying fit for use is undergoing the process of the official prototype test, of which a positive acknowledgement of the type of the vehicle is the purpose with applicable standards of the safety in the aspect widely understood, in particular - of passive safety. The vehicle is being subjected among others to the crash attempt. The typical test, applied for years is based on strucking by the vehicle into the flat stiff obstacle with the velocity 50 km/h. Among others providing for the required space surviving inside the vehicle is the condition of passing the test positively and not-crossing the border values by indicators associated with the influence of the decelerations on the body of the driver and the passengers. However conditions of conducting such test are idealized and are not fitting in with real terms, in which collisions of vehicles often take place not centrally and at higher speeds. Hence the large accident toll, in which automobiles, regarded safe, experiences aren't ensuring conditions.

In the article the traffic accident, in which despite the higher speed in the moment of the collision, the driver and the passenger didn't sustain the injury, was discussed. The accident consisted in colliding of vehicles Volkswagen Golf, model from 2009 (so-called "VI Golf") with Mercedes 190 from 1987 (W201 model). Volkswagen moved along the road, and Mercedes executed a maneouver of returning. As the result of the accident the driver of the Mercedes was killed on the spot, however the driver of the Volkswagen and his passenger sitting on the front right armchair sustained no injury.

2. Place of the traffic accident

The accident took place in the built-up area within a little town on the straightaway of the roadway of the province road. The width of the roadway in the place of the event was 7 meters. The roadway is divided in 2 traffic lanes, divided with broken line. Roadsides were sandy, horizontally of the surface of the roadway. On the left side of the road were found three asphalt entries into premises.

In the place of the traffic accident were substantiated skid marks with the active ABS system of Volkswagen 9.4 m long, signs of the friction between tyres and road surface of both vehicles, the field of dispersion of piece of broken glasses and chips of plastics and post-accident location of the vehicles.

Weather conditions during the road accident were good: sunny, without precipitations and other phenomena limiting the visibility. Asphalt roadway in the place of the accident was dry, clean, smooth. For these conditions the rate of the adhesion was accepted on the asphalt surface [6]:

$$\mu_1 = 0.7$$

and on the hard shoulder:

$$\mu_2 = 0.2.$$

The sketch of the place of the accident was shown in Fig. 1.

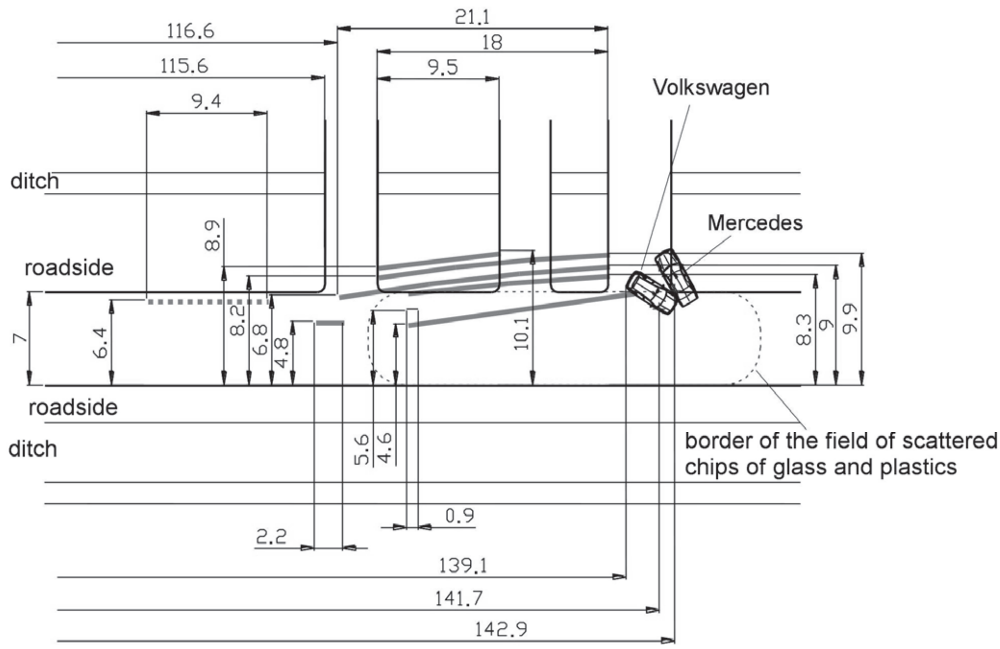

Fig. 1. Sketch of the place of the traffic accident

3. Reconstruction of the traffic accident

As a result of the collision the front part of the vehicle Volkswagen was damaged and the side part of the vehicle Mercedes – Fig. 2.

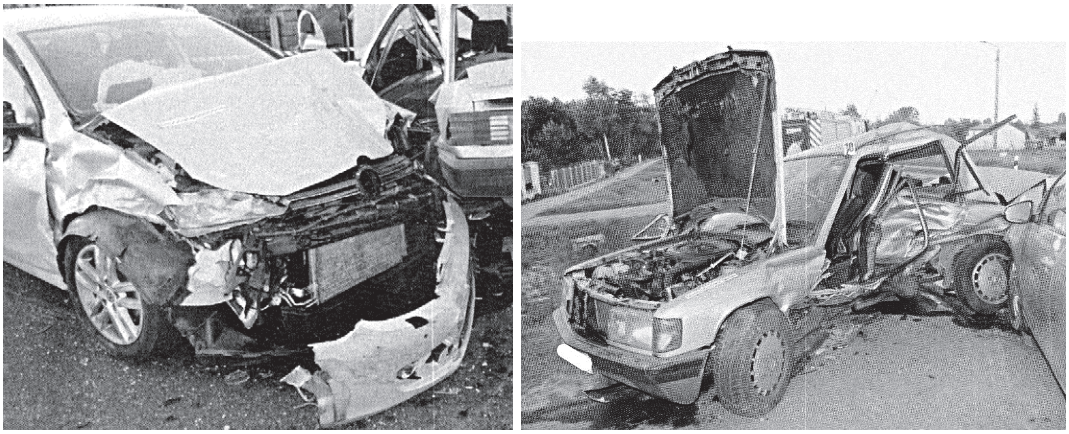

Fig. 2. Post-accident damage of vehicles

On the basis of vehicles damage it is possible to determine their relative location in the moment of collision – Fig. 3. However, taking into account relative location of substantiated tracks on the roadway – place of the traffic accident – Fig. 4. Vehicle Volkswagen left skid marks with ABS. The skid marks are parallel to the roadway axis. Location of the vehicles along the roadway was determined through the location of primary tyre-roadway friction marks.

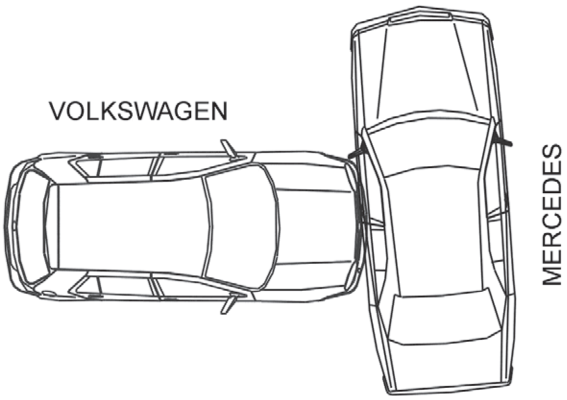

Fig. 3. Relative position of the vehicles in the moment of collision determined on the basis of bodywork deformation

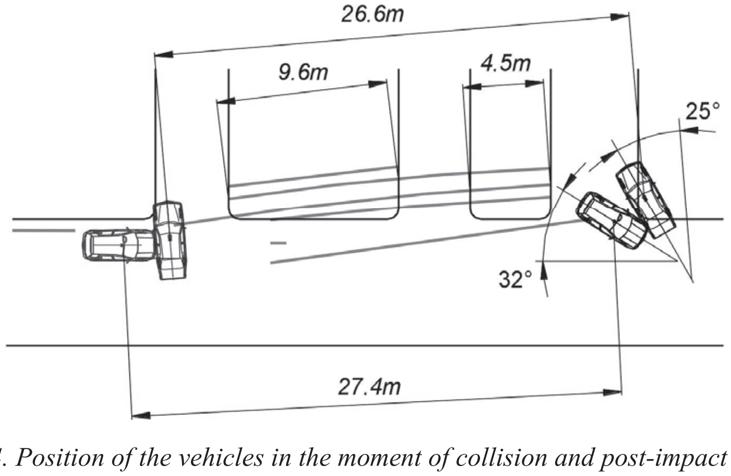

Fig. 4. Position of the vehicles in the moment of collision and post-impact transfer

Typical course of this type of reconstruction is based on determining the velocity of vehicles at the beginning of post-impact motion phase, and hence at the end of the impact phase. Next, the impact phase is considered, determining velocities of the vehicles in the moment they first contacted. Values determined in this way are velocities of the vehicles in the end of pre-impact phase [2].

The problem of the reconstruction of described traffic accident is complicated. Vehicle Mercedes in the post –impact motion was moving partly on the asphalt surface and partly on the sandy roadside. Applying typical calculation schema [3], based on determining the velocity of vehicle Mercedes in the end of impact phase, adopting the motion of the vehicle with the wheels lock-up (side motion of the vehicle) on homogeneous asphalt surface, abnormally high velocity of vehicle Volkswagen is obtained, which does not correspond to the traffic conditions in the place of the accident.

For the calculations the following masses of the vehicles were put:

– Mercedes:

$$m_M = 1495 \text{ kg},$$

equal to the bare mass of the vehicle (1420 kg) and estimated mass of the driver (75 kg),

– Volkswagen:

$$m_{VW} = 1365 \text{ kg},$$

equal to the bare mass of the vehicle (1215 kg) and estimated mass of the driver and the passenger (2 x 75 kg).

Vehicle Mercedes in the post-impact motion was moving partly on the asphalt surface and partly on the sandy roadside (see Fig. 1). On the basis of the sketch of the place of the accident and the course of tyres marks, the participation of tyres friction stretches of vehicle Mercedes on the asphalt surface was stated (Fig. 4):

$$x_a = \frac{2 \cdot 26.6\text{m} - 9.6\text{m} - 4.5\text{m}}{2 \cdot 26.6\text{m}} = 0.73\,. \tag{1}$$

For the estimation of vehicle Mercedes in the end of impact phase Burg [1] method was used. This method makes it possible to estimate the initial velocity of the vehicle in non-steady-state motion (displacement with the yaw motion), knowing the linear and angular displacement of the vehicle and additionally the state of locking of the following wheels of the vehicle and the initial direction of the vehicle motion (longitudinal or lateral) [4]. For the needs of the reconstruction, this method was modified, in case of complicated vehicle motion on two types of the road surface. Instead of the values of adhesion coefficient, the computational coefficient as the weighted average of the adhesion coefficients of asphalt surface and roadside was applied. Because of that the average computational deceleration of the vehicle was estimated as follows:

$$a' = \left[x_a \cdot \mu_1 + (1 - x_a) \cdot \mu_2\right] \cdot g \cdot \left[f_H + (1 - f_H) \cdot \sin \Psi_m\right]. \tag{2}$$

For the yaw angle of the vehicle $\varphi_M = 25^o < 60^o$:

$$\sin \Psi_m = \sin \frac{\varphi_M}{2} = \sin 25^o = 0.216.$$

Because two wheels of vehicle MERCEDES (front, not driven) were rolling during the post-impact motion, the coefficient of vehicle braking forces was assumed as follows:

$$f_H = 0.5\,.$$

Average deceleration of the vehicle equaled as follows:

$$a' = \left[0.73 \cdot 0.7 + (1 - 0.73) \cdot 0.2\right] \cdot 9.81\text{m/s}^2 \cdot \left[0.5 + (1 - 0.5) \cdot 0.216\right] = 3.37\text{m/s}^2 \tag{3}$$

and from this the value of vehicle velocity in the end of the impact phase results:

$$v_{MZ} = \sqrt{2 \cdot a' \cdot S_M} = \sqrt{2 \cdot 3.37\text{m/s}^2 \cdot 26.6\text{m}} = 13.4\text{m/s}\,.$$

Because after the impact the vehicle Volkswagen was moving behind the vehicle Mercedes, its velocity was close to the velocity of Mercedes, so it was assumed:

$$v_{VZ} = 13.4\text{m/s}\,.$$

The velocities in the beginning of post-impact phase estimated in this way were equal to the velocities in the end of impact phase. However the velocities of the vehicles directly before the impact were estimated on the basis of the principle of linear momentum conservation.

Linear momentum of the vehicles after the impact in the direction parallel to the roadway axis, approximately in the direction of post-impact motion direction equaled for the vehicles as follows:

– vehicle Volkswagen:

$$p_{Vz} = m_V \cdot v_{Vz} = 18\,290\text{N} \cdot \text{s}\,, \tag{4}$$

– vehicle Mercedes:

$$p_{Mz} = m_M \cdot v_{Mz} = 20\,030\text{N} \cdot \text{s}\,. \tag{5}$$

Because in the moment of the impact the vehicle Mercedes was moving approximately normally to the axis of the roadway or did not move, which cannot be explicitly established, its linear momentum in the direction parallel to the axle of the roadway was practically equal zero. Therefore, from the equation of the principle of linear momentum conservation in direction parallel to the roadway axis the relation results:

$$m_V \cdot v_V = p_{Vz} + p_{Mz}\,, \tag{6}$$

from which the velocity of vehicle Volkswagen results , directly before the impact:

$$v_V = \frac{p_{Vz} + p_{Mz}}{m_V} = \frac{18\,290 + 20\,030}{1365}\text{m/s} = 28.1\text{m/s} = 101\text{km/h}\,.$$

On the basis of the length of substantiated marks of braking of Volkswagen, it is possible to estimate its velocity in the moment, when the driver began defensive maneouver and the distance, from which he could notice Mercedes on the road.

3.1. Deceleration of Volkswagen

Decelerations acting on dummy during the crash attempt of the vehicle with the velocity 50 km/h are about 30g (g – gravitational acceleration). Knowing the approximate time of the phase of vehicles impact lasting, during which the change of vehicle velocity is taking place:

$$t_Z = 100...200\text{ ms},$$

it is possible to estimate the average value of deceleration acting on the persons being in Volkswagen in the moment of the impact:

$$a_{\acute{s}rVW} = \frac{v_V - v_{VZ}}{t_Z} = (73.5...147)\text{m/s}^2 = (7.5...15)g\,. \tag{7}$$

Relatively not high value of average deceleration of Volkswagen results from the fact, that Volkswagen hit the side of Mercedes, between its axles. The bodywork of the vehicle in side part has the lowest stiffness. Energy absorption of the structure of the bodywork when hitting its side part is even 5…10 times lower compared to the front part. Because of this, deep deformation of side part of Merdeces took place (see Fig. 2), practically to the half a width of the vehicle. It resulted in relatively slow increase of the deceleration of the vehicles in the impact phase.

In similar way it is possible to estimate the average accereration of vehicle Mercedes:

$$a_{\acute{s}rM} = \frac{v_M}{t_Z} = (67...134)\text{m/s}^2 = (6.8...13.6)g\,. \tag{8}$$

It was slightly lower than deceleration of Volkswagen. However, the driver of Mercedes was in the area of the deformation zone.

4. Conclusion

Deceleration of the person being in the vehicle and the time of deceleration acting during the traffic accident is the most important factor, that decides about the possibility of surviving of the person involved in traffic accident. Analyzed case shows, that the person involved in the accident can survive and even avoid injuries during the impact with the obstacle with high velocity provided that the hitting takes place in the element that would let decrease the velocity on relatively long stretch of the road.

The above example shows also the effects of lack of energy compatibility of impacting structures of the vehicles – minimizing, or even avoiding the injuries of the bodies of the persons being in stiffer vehicle and simultaneously violating of the zone of surviving in the vehicle with the lower stiffness.

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