AN APPROACH TO IMPROVE PASSIVE SAFETY BY MEANS OF "ACTIVE BUMPER" WHICH COMPENSATES THE LUCK OF CARS COMPATIBILITY AS WELL AS DIFFERENT AGGRESSIVITY WHEN FRONTAL IMPACT OF A LARGE TRUCK AND A MOTOR CAR IS UNDER CONSIDERATION

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Abstract

The seriousness of an impact "large truck – motor vehicle" has been exhibited. The procedures of truck and motor cars crash testing were compared in order to point out the necessity of cars crashworthiness investigation in terms of compatibility and impacts between vehicles with large difference in mass and rigidity. Furthermore the paper explains a course of frontal impact between large truck and motor car in order to proof the necessity of cars compatibility as well as aggressivity investigation. The mass effect along with rigidity effect was exhibited as well. Moreover, the paper explains the design as well as objectives of the passive safety devices of both motor car and large truck. The concept of another, innovative passive safety device such as "active bumper" has been emphasized. Its working principia, adaptive control as well as the diagrammatically presented design were pointed out. The bumpers control is very difficult as it will be entirely independent from a driver and it has to operate in random condition, therefore, the paper contains a proposition of controlling algorithm of the "active bumper". It also contains explanation of adaptation of the "active bumper" with various working condition as well as consideration of the "active bumper" application with various types of large trucks design.

Keywords: *safety, crash test, compatibility, aggressivity, occupant protection, accident*

1. Introduction

Safety of cars produced nowadays is one of most important concern of manufactures. Vehicles are being constantly improved by applying innovative solution in order to escalate passive and active safety. Paradoxically, in order to examine of vehicle safety it is necessary to destroy it during crash tests. Crash tests are sets of measurements taken during simulated most frequently occurring accidents. However, different tests are performing for different vehicle class. Heavy trucks are tested by simulating accidents which are most common for this type of vehicles. For example crashing trailer against rear wall of passenger cabin of the truck or examining cabin durability by statically applying large weight. Passenger cars are tested by simulating frontal, rear, side and pedestrian impact. There are no legal requirements for those two kinds of vehicles to be tested in terms of truck – passenger car impact. However, there are projects and groups established in order to investigate this kind of accidents and eventually propose the tests procedures for determining safety during the accident. Presently, heavy trucks are only required to be equipped in front under run protection device (FUPD) which is only a rigid bumper fixed in lower position in order to partially compensate an incompatibility. Special kind of energy absorbing FUPDs is not legally demanded. However, taking the large difference in mass and in stiffness of a truck and a passenger car as well as the crash mechanics into account, it can be fairly stated that installing energy absorbing FUPDs is very beneficial in terms of safety and crash severity.

2. Crash compatibility and aggressivity

The compatibility of vehicles is one of the most important factors as far as vehicles safety is concern. Due to tremendous variability of cars design, it is impossible to ensure crash accidents of this same model and consequently construction. Unfortunately, the design of the cars cannot be changed in level entirely ensuring the unification. Therefore, vehicles are incompatible in terms of their stiffness geometry and mass. It is accepted that two colliding vehicles are compatible when the deformation caused by impact is similar in both cases. Determination of cars compatibility is rather difficult as there is no metric measure of it [8]. Therefore the notion of vehicles aggressivity has been established. Aggressivity is defined to be the number of fatalities/injuries in the vehicles struck by the subject vehicle divided by the number of subject vehicle registrations [4].

3. Frontal impact of large truck and passenger car

The severity of frontal impact of the large truck and passenger car is explain with aid of lumped mass model depicted in Fig. 1. It has been assumed that during this impact an under running did not occurred. The lumped model exhibits large truck (on left side) and passenger car (on right side) travelling with relative velocity of 50 km/h. Both vehicles have the deformation zones appropriate to their mass class. It also should be noted that vehicles deformations will be different with respect to impact speed. In order to visualise it, three cases will be under consideration. In first case a standing truck being impacted by a car with speed of 50 km/h. In second case standing passenger car, is being impacted by a truck with speed of 50 km/h. In third case a passenger car travelling with speed of 26 km/h impacting a truck travelling with speed 24 km/h [5]. The results of the test are depicted in Fig. 2. As it can be seen in Fig. 2a the velocity and displacement for considered cases are different. However, taking the relative velocity of the passenger car into account it can be notice that the velocity changes identically for three cases [5]. Figure 2b exhibits the body and engine deceleration during the impact. In case of the truck's body location the deceleration curves are on top of each other. Similarly, those deceleration curves at the engine location of for the three cases are identical. Based on his test it can be fairly stated that a crash of two vehicle severity, such as deceleration, energy absorbed and dissipated is highly dependent on the relative velocity as well as mass and rigidity ratios of those two types of vehicles [5].

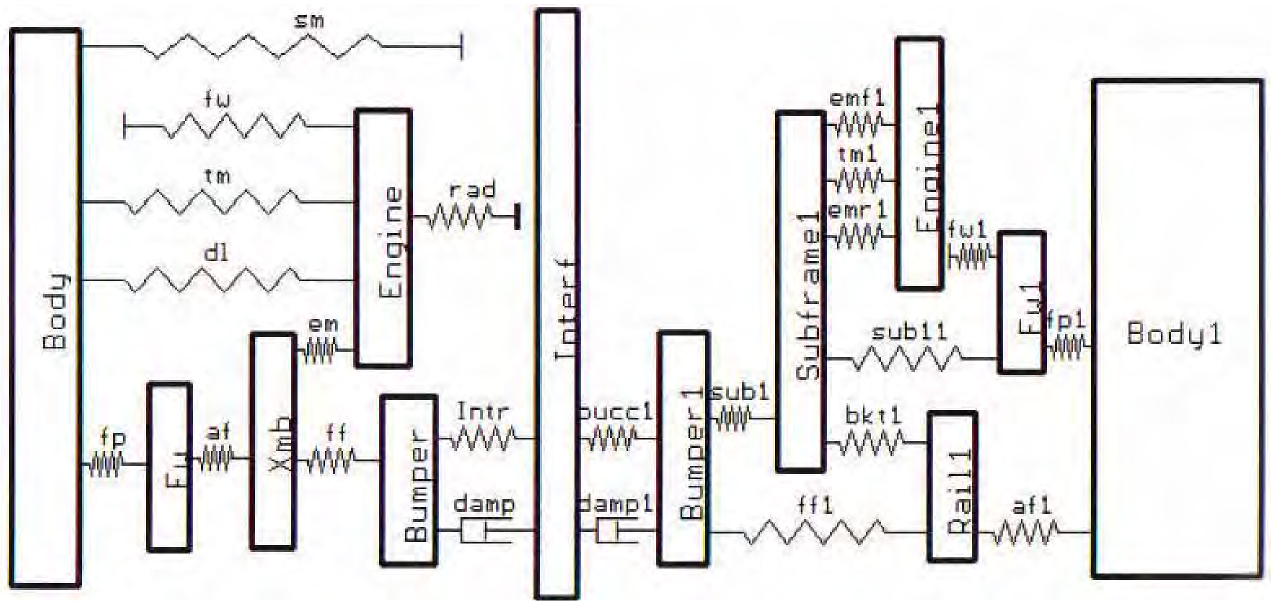

Fig. 1. Lumped mass model of a vehicle to vehicle impact [5]

4. Mass and rigidity influence on vehicle crashworthiness

In general, mainly the longitudinal, of the vehicle is responsible for accumulating impact energy. Front of the vehicle is capable of dissipating approximately 65% of whole energy. The rest 35% is

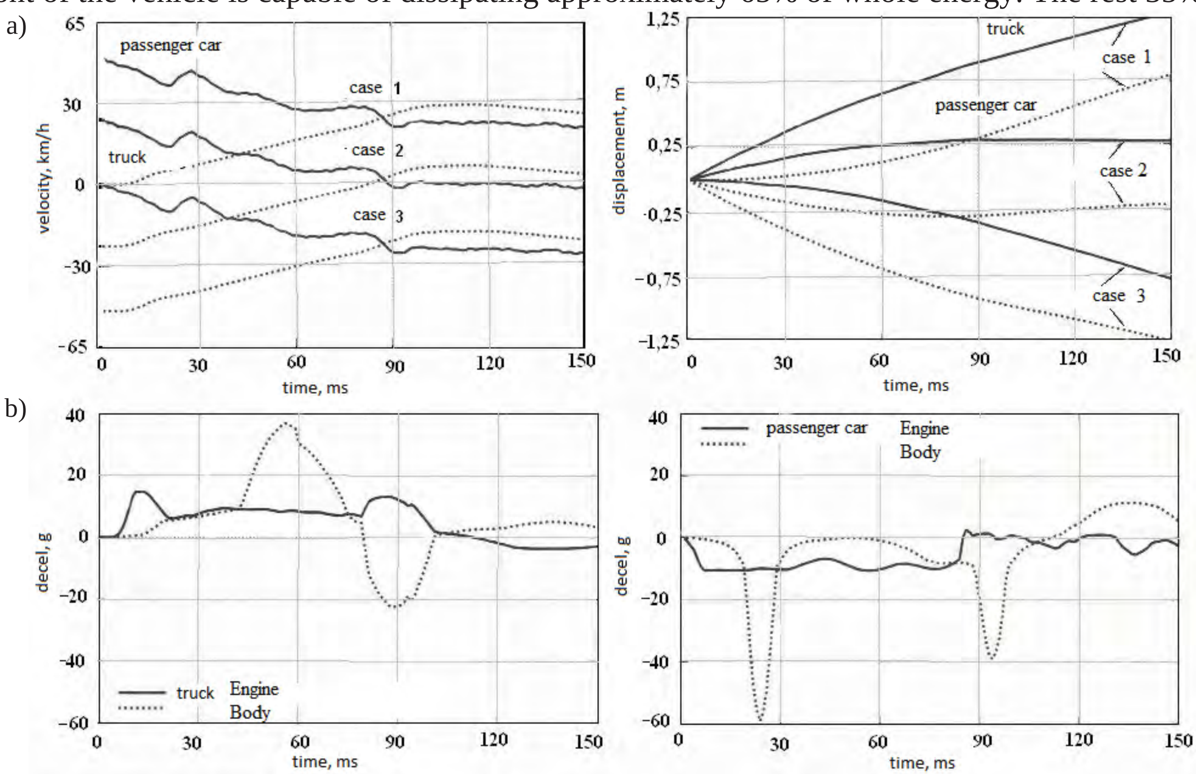

Fig. 2. The results of the vehicle to vehicle test [5]

taken over by front part of a car's body. The force distribution on front of the passenger car with respect to distance of the intrusion is depicted in Fig. 3 [5]. Only the deformation zone of the truck can be changed in sufficient level. Extending it for 1 m decreases the deceleration of the passenger compartment for almost 50%. It is easy to prove mathematically. Taking the principle of conservation of momentum (1), the different masses of vehicles into consideration. Moreover, knowing that kinetic energy of impact is equivalent to work produced by the deformation process (2), it is easy to determine the deceleration of the passenger compartment (3). The last equation shows that the passenger compartment deceleration is inversely proportional to the distance of deformation, hence by extending the deformation zone, the acceleration of passenger compartment decreases [8].

$$m_C \Delta v_C + m_T \Delta V_T = 0\,, \tag{1}$$

$$\frac{m_T v_B^2}{2} = F s_T \Rightarrow F = \frac{m_T v_B^2}{2 s_D} = m_C a_C\,, \tag{2}$$

$$a_C = \frac{m_T}{2 s_D m_C} v_B^2\,. \tag{3}$$

where:

m_T, m_C - mass of the truck and passenger car respectively,
s_D - the distance of intrusion,
a_T, a_C - the acceleration of the truck and car passenger compartment respectively,
v_B - - normalized velocity of barrier crash test.

The distance of intrusion is highly dependent of stiffness of the construction. The stiffness of a vehicle is crucial in terms of passive safety. Most often cars have a local stiff structure within much larger area of weaker structure [8]. It is obvious that the construction is different for various types of vehicles. This kind of incompatibility causes penetration of the weaker parts of the vehicle by the stiff parts of other one. This may result in penetration fork effect or over-ride [9].

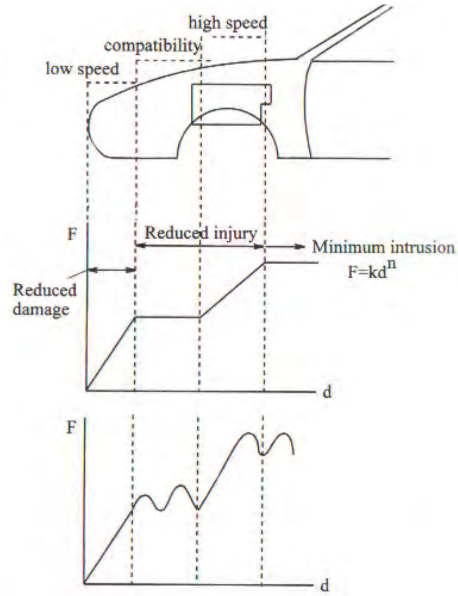

Fig. 3. The force distribution on front of the passenger car with respect to distance of the intrusion [5]

5. Heavy vehicles passive safety devices

All kinds of vehicles, manufactured nowadays, have to be equipped in passive safety devices. Heavy truck has to be additionally equipped in systems which compensate the luck of cars compatibility. System which prevents sliding smaller car underneath of the truck is called FUPD (Front Under run Protection Device). Mostly those kinds of systems represents bumper placed in lower position so the compatibility is partially fulfilled (see Fig. 4). The FUPD position as well as the behaviour during impact is described in ECE 93 Regulation.

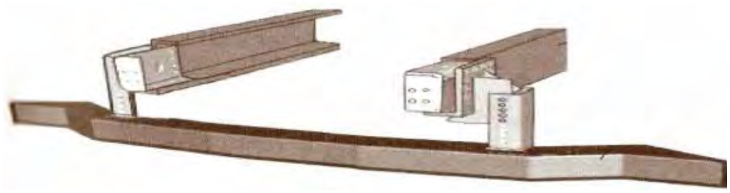

Fig. 4. Rigid FUPSD [5]

According to the ECE R 93 regulation a FUPD has to be fitted on the height of 100 mm from the ground [2] when the vehicles used for the carriage of goods and having a maximum mass exceeding 3.5 tonnes but not exceeding 12 tonnes [3] are under consideration. When vehicles used for the carriage of goods and having a maximum mass exceeding 12 tonnes [3] the FUPD has to be fitted on height of 120 mm. It is also established that the in case of frontal impact, front of the truck cannot be deformed more than 400 mm [2].

There are several types of FUPD's design. The difference mainly consists on rigidity of the bumper beam. The construction which is capable of accumulating impact energy has been invented as well. The FUPDs were crash tested by VC-COMPAT project . The tests had proven that it is beneficial in terms of safety to install FUPDs capable of accumulating part of impact energy. It appears that special kind of FUPDs shown Fig. 5 and 6 are capable of accumulating 16% of total energy when the non rigid, aluminium foam blocks are applied (see Fig. 5). The FUPD with the support brackets showed capability of absorbing even 15% more energy than in case of previous device (see Fig. 6). In comparison, standard rigid FUPDs has only prevent from under running of the smaller vehicles [7].

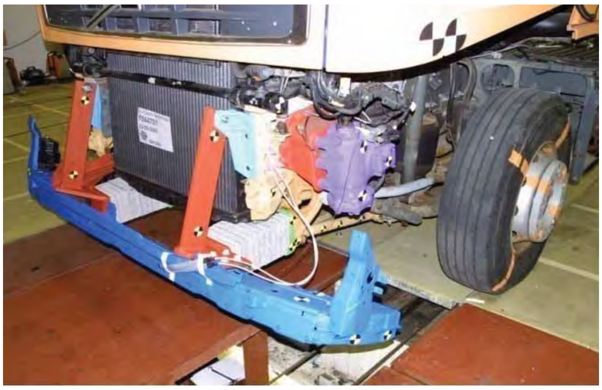

Fig. 5. Special kind of FUPDs with non rigid, aluminium foam blocks [7]

Fig. 6. Special kind of FUPDs with rigid, support brackets [7]

6. The "active bumper" as a FUPD improvement

As it was previously pointed out it is very beneficial in terms of safety to deploy to a truck a under run protection device which is capable of accumulating part of impact energy. Therefore the concept was established.

The concept of the "active bumper" consists on installing actuators to a truck's frame. FUPD will be fixed to the pistons of the actuators. During phase of safe driving (no obstacles approaching) the pistons will be moved backwards, hence the system will be fully hidden underneath of the truck and consequently appearance of the vehicle will not be significantly change. The actuators will rapidly move pistons forward when the approaching obstacle is detected. The system will be equipped in dual controlling module. The velocity of approaching car will be determined by means of radar (RTC). The radar sensor shall send out a short focused, high-power pulse of radio waves at a known frequency (77 GHz). The radio waves will reflect form approaching car. The speed will be determined by means of a Doppler effect. The returning signal will be received by radar's sensor and then the information will be sanded to the control unit (CU) which determines whether established boundary condition are breached and an impending collision is imminent. The speed as well as distance between vehicles can be also determined by means of Lidar (Light Detection And Ranging). The laser-based systems are relatively cheaper, less sensitive on atmospheric condition and capable of cover larger distance. The velocity of approaching, and more importantly the distance between two colliding cars, will be additionally measured by means of second, auxiliary module. The second module is simply a laser rangefinder. The reading provided by this device will constantly sand to the CU where the change of distance is transferred into speed. The “active bumper” will be activated immediately after control unit “founds” established boundary condition as breached. The piston rots with FUPD will be thrown for some distance forward. The method of activating the “active bumper” will be also dual. The piston motion will be provoked by pyrotechnic explosion. When an impending collision is detected, a signal is sent to the actuator’s electrical contacts on the initiator’s pyrotechnic chamber. The ignition will be initiated by current passing through filled with explosive material ignition head. The ignition head will explode when the current "reach the threshold level. Explosion of the ignition head will provoke detonation of pyrotechnic material which preliminarily will be separated from the initiator. The detonation will rapidly change pressure on both sides of piston, and in consequence the piston rot will be thrown forward. The second (supporting) activating method will be simply compression spring which will help to overcome an inertial force. When the piston rots with applied FUPD, will be “fired” forward, hence ready to intercept approaching car, all valves will be immediately closed. Therefore, during impact piston rots pushed by the impacting car will experience large resistance caused by incompressible gases. The actuators will be equipped with safety valves which will be responsible for releasing part of the gas with respect to magnitude of pressure that occurred during pushing the rots by the impacting car. The safety valves will be opened by means of the pressure inside the actuator. The higher pressure, the larger amount of gas will be released. The “active bumper” will dissipate part of impact energy. The energy will be further accumulated by means of standard safety systems of both passenger car and truck. Diagrammatic design of the “active bumper” is depicted in Fig. 7.

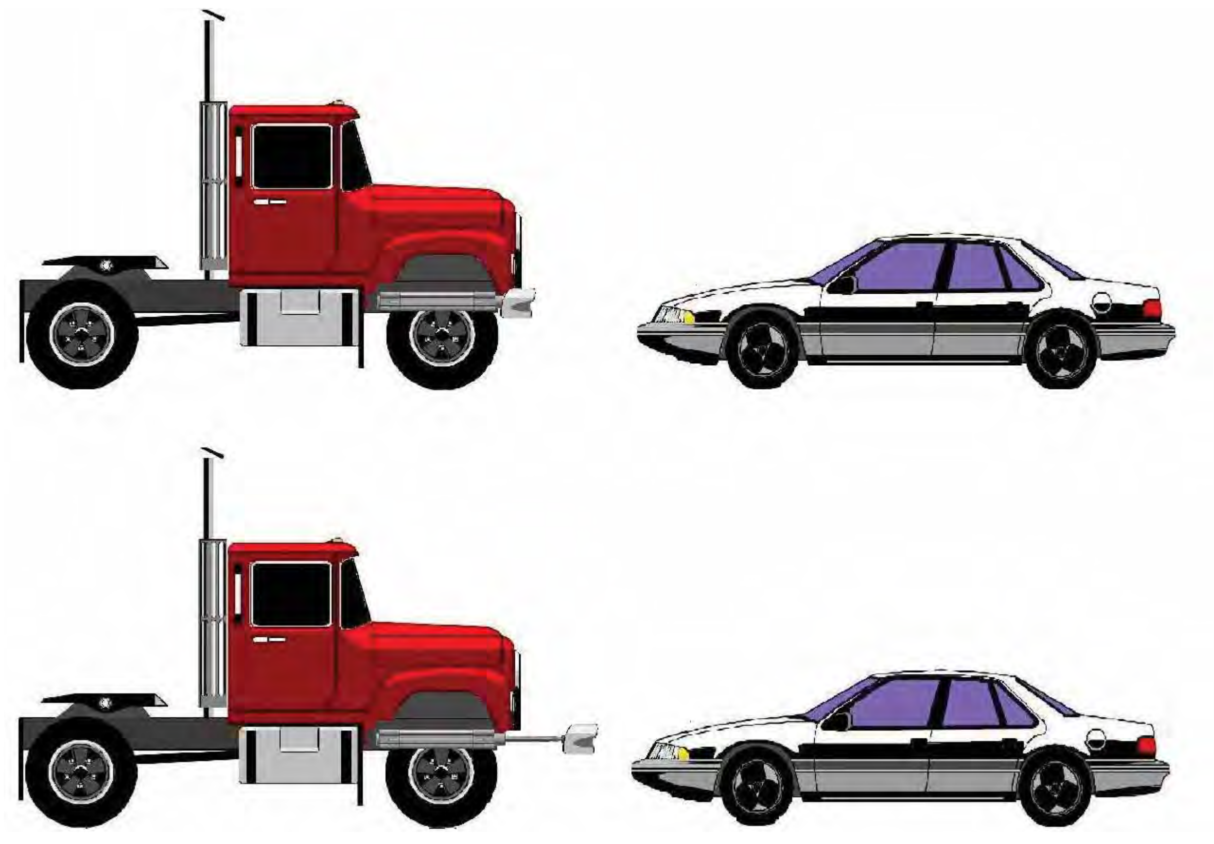

Fig. 7. Diagrammatic design of the „active bumper” [1]

7. Control of the “active bumper”

In order to ensure correct functionality of the “active bumper” it is necessary to establish boundary condition. As it has been already mentioned, severity of an accident is highly depended on velocity, mass and rigidity ratios. During extremely short time preceding the impact it is impossible to estimate the mass and rigidity ratios. Therefore, the only estimative factor is velocity. Since, predominantly both vehicles will be in motion, the relative velocity should be taken into account. Another crucial factor is distance between those two vehicles. "Firing" the "active bumper" when the passenger car is to close to the truck will cause even more danger, therefore it cannot be performed. The control algorithm is depicted in Fig. 8. The control unit (CU) will be constantly provided with information about velocity of the truck. If the approaching hazardous car is detected, sensors will send information about change of position of the object. The approaching vehicle will be monitored until it CU categorises it as "not threaten" or as a "threaten". If the car is categorised as "not threaten" no action shall be executed. The car shall be considered as a "not threaten" when it will not be at the collision course nor the relative velocity nor distance between vehicles ($L_s < L_{max}$) exceeds the established value. The car will be considered as "threaten" when at least one of the conditions (speed, distance, course) is broken. In that case CU is preparing to deploy the "active bumper". If the passenger car maintains on the collision course travelling with speed established as danger ($V > V_{max}$), the "active bumper" will be deployed. However, no action will be executed if the car changes course on the safe one.

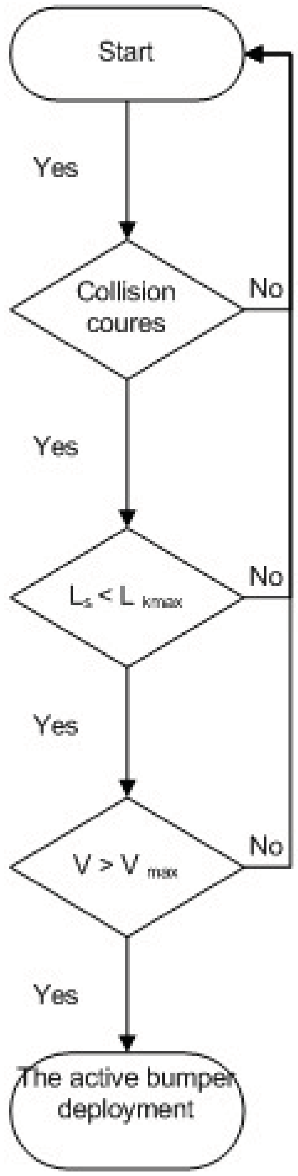

Fig. 9. The active bumper control algorithm

It has been estimated that the “active bumper” requires maximum of 0.5 s to be deployed. Based on this the threshold relative velocity is estimated to be 60 km/h. That speed and time of deploying extorts the minimum distance of 15 m between vehicles. However , those values will be verify and adjust during test in order to ensure maximum safety during impact of large truck and passenger car.

8. Conclusion

The frontal crash of incompatible vehicles causes large number of death or life treating injuries. A situation when passenger car hits a truck is equivalent to impact of passenger car crashing against a rigid wall. In order to reduce impact severity the stiffness of vehicles is increased. However, this solution can also bring undesirable effect due to the fact that deformation zone will be shortening and consequently impact energy will not be dissipated in sufficiently. Unfortunately, the number of methods concerning change of vehicles front end design is highly limited. Hence the proposition of an “active bumper” is a step forward as far as the crash severity is concern. The “active bumper” will artificially extend the deformation zone of a truck. The bumper will be design in the way allowing operating along with existing systems and supporting them. Moreover, the “active bumper” will be system fully adjustable for any kind of truck, as it is design, as a separate additional device that is fixed to the truck frame. Certainly, this solution will help to improve passive safely during frontal impact of vehicles with significantly different mass.

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