9th International Scientific Conference Transbaltica 2015

Energy Absorbing Hydro Pneumo Mechanical Mechanism to Enhance Passive Safety in Motor Vehicles

Marijonas Bogdevičius*, Rolandas Vitkūnas

Vilnius Gediminas Technical University, Plytinių g. 27, LT-10105 Vilnius, Lithuania

Abstract

The article describes one of the ways to enhance safety in cars. The topic is addressed by analyzing how to absorb kinetic energy during a car collision with an obstacle. The article analyzes opportunities to convert motor vehicle’s kinetic energy into another type of energy in the case of collision. For this purpose, various mechanical, hydraulic or pneumatic devices are normally used. Such devices are designed to absorb collision energy and reduce or eliminate its impact on the driver, the passengers or cargo in the motor vehicle and are typically referred to as additional elements of safety to the passenger and cargo. The energy absorbing device described in the present article incorporates hydraulic, pneumatic and mechanical mechanisms. The layout of the device presented in the article includes mathematical description of mechanical, pneumatic and hydraulic processes in the equipment. Analysis of the developed mechanism employs a special application to calculate major parameters of the motor vehicle and the installed device. The article also includes sample calculations.

© 2016 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords: vehicle safety; hydro mechanical device; absorption of kinetic energy.

1. Introduction

Importance of passive security in motor vehicles has been growing for decades. Safety of the passenger and the cargo is one of the key issues in transport security. Safety during a car collision with an obstacle is typically ensured.

* Corresponding author

E-mail address: marijonas.bogdevicius@vgtu.lt
by absorbing excessive kinetic energy. To absorb the kinetic energy during a car collision and convert it into another type of energy, modern motor vehicles use a range of mechanical, hydraulic and pneumatic devices.

Such energy absorbing devices are designed to absorb collision energy and reduce or eliminate its impact on the driver, the passengers or cargo in the motor vehicle. At the same time, such devices would eliminate the need to use air bags or might be used as an additional means of safety to passengers or the cargo.

The energy absorbing device is designed as a hydraulic, pneumatic and, at the same time, mechanical device as all of the latter expose specific characteristics that may positively contribute to the overall construction.

The layout of the device presented here includes mathematical description of mechanical, pneumatic and hydraulic processes in the equipment.

Analysis of the developed mechanism employs a special application to calculate major parameters of the motor vehicle and the installed device: the trajectory, velocity, acceleration and kinetic energy of the motor vehicle. The calculations help to determine significance and variation of the parameters of individual elements of the device.

2. Analysis of the conducted work

To absorb motor vehicle’s kinetic energy during a collision, various hydraulic, pneumatic or mechanical solutions may be used. Review and analysis of the conducted research distinguishes a hydraulic system (US 20100122864 A1), that reduces impact suffered by the chassis. Also a pneumatic shock absorbing system (patent CN 201989737) and adjustable shock absorbers (patent DE 10 2010 051 872 A1) are widely used to reduce impact on the chassis. The chassis may be equipped with various mechanical or electromechanical safety devices (patent CN201833977, WO2013137516 A1) that reduce collision forces when a car with a specially equipped chassis is hit by another motor vehicle.

Mechanical devices (Gumuła, Doruch 2003; Gumuła, Łągiewka 2005, 2006, 2007) may also be used. Design of the construction was mostly affected by works by Georg Piontek, Stanislaw Gumula and Premyslaw Lagievka. Their works describe a mechanism that changes the force of the forward motion into rotational inertia the flywheel. The works also present the principle scheme of the mechanism that changes the linear force and kinetic energy of the collision into the flywheel’s energy and torque. They also describe design of the mechanism, but present neither calculations (as in instructional books (Bogdevičius, Šukevičius 2012; Bogdevičius 2012, 2012)) of its individual elements nor works of optimization. Another drawback of the presented mechanism is its large dimensions.

3. Layout of the energy absorbing hydro pneumatic mechanical device that enhances passive safety in motor vehicles

A motor vehicle with the mass $m_1$ has an energy absorbing hydro pneumatic mechanical device that enhances passive safety in the motor vehicle (Figure 1). The motor vehicle is coupled with a bumper the mass of which is $m_2$. The coupling between the motor vehicle and the bumper is characterized by rigidity $k_{12}$ and shock absorbing $c_{12}$. When the motor vehicle hits an obstacle (the obstacle is characterized by rigidity $k_0$ and shock absorbing coefficient $c_0$), the part of the device attached to the bumper begins to move at the velocity $v_1$. The lever of the device on the left side of the hydraulic cylinder presses the liquid increasing pressure $p_2$. The respective piston areas of the hydraulic cylinder on the left and the right sides are $A_1$ and $A_2$. The hydraulic cylinder absorbs the initial impact. Perforation in the cylinder partly equalizes pressure on both sides of the hydraulic cylinder ($p_1$ and $p_2$).

The rack bar attached to the lever lies in the cylinder and moves, on a collision, to the right rotating the gear wheel mechanism at the same time (the radius of the gear wheel, referred to as the first gear wheel, is marked $R_1$ in Figures 1). On a collision, the gear wheel moving to the right rotates the mechanism and finally (on reaching the end point on the right) comes out of contact with the gear wheel with the radius $R_1$, leaving the gear wheels and other elements of the mechanism in rotation and movement.

The design and parameters of the mechanism have to be set so as to allow the hydro cylinder, the mechanical assembly of the rack bar and the gear wheels, the traveler and the crank with the additional mass on the rod and the pneumatic cylinder to maximally absorb kinetic energy passed to the motor vehicle at the moment of collision with an obstacle. Also, the velocity of the motor vehicle has to maximally decrease, but the acceleration of the motor vehicle may not exceed the value that can cause risk to the driver and the passengers.
The system of equations of energy absorbing hydro pneumatic mechanical device is equal (Bogdevičius, Šukevičius 2012; Bogdevičius 2012, 2012):

\[
[M]\{\ddot{q}\} = \{F_q(q, \dot{q}, p, t)\},
\]

\[
\{\ddot{p}\} = \{F_p(q, \dot{q}, p, t)\},
\]

where \([M]\) is matrix of mass; \(\{F_q(q, \dot{q}, p, t)\}\) is load vector; \(\{\ddot{q}\} = \frac{d^2 q}{dt^2}\) is vector of accelerations; \(\{p\}\) is vector of pressures in the volumes of hydraulic and pneumatic cylinders.

4. Development of the application

To carry out the exact calculations of the parameters of the energy absorbing hydro pneumatic mechanical device based on the formulas described in chapter 3, a special application has been developed.

The application and subroutines to carry out the relevant calculations were programmed in FORTRAN. The calculations include the following parameters:

- masses of the motor vehicle, the bumper, the crank, the traveler, the pneumatic piston and the gear wheels;
- radii of the gear wheels;
- moments of inertia of the gear wheels;
- distances from the points of connection of the traveler, the crank and the additional mass to the corresponding centers of gravity;
- diameters of pistons and the rods;
- the number and diameters of the holes in the hydraulic piston;
- clearance between the rack bar and the gear wheel and clearance between gear wheels (the second and the third gear wheel);
- elasticity, friction and density of the hydraulic fluid.

5. Calculation results

The calculations include original parameters of the device. A gross vehicle weight 1000 kg, bumper 20 kg. Velocity of the vehicle 60 km/h (speed limit in the cities 50 km/h, but real speed 10 km/h are higher), selected parameters of the hydraulic and pneumatic cylinders Weights and radii of the gear wheels, weights and lengths of the traveler and the crank. The major parameters are presented in the table below.
Further analysis of the device parameters comprises vehicle and bumper thrust, velocities, and accelerations, turning angles of the gearwheels and the traveler, piston strokes and velocities and mechanism inertia. The most important among them are the thrust, velocity, acceleration and kinetic energy of the vehicle.

Results obtained during the first 0.45 seconds are graphically presented in figures 2–5.

<table>
<thead>
<tr>
<th>Selected parameter</th>
<th>Parameter value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rack bar to gear wheel engagement throw</td>
<td>100</td>
</tr>
<tr>
<td>Traveler length, $L_1$, mm</td>
<td>150</td>
</tr>
<tr>
<td>Traveler $L_1$ weight, kg</td>
<td>2</td>
</tr>
<tr>
<td>Crank length $L$, mm</td>
<td>400</td>
</tr>
<tr>
<td>Crank $L$ weight, kg</td>
<td>3</td>
</tr>
<tr>
<td>Additional mass rod $L_3$ length, mm</td>
<td>100</td>
</tr>
<tr>
<td>Additional mass at point $C_4$, kg</td>
<td>5</td>
</tr>
<tr>
<td>Radius of the first gear wheel $R_1$, mm</td>
<td>70</td>
</tr>
<tr>
<td>Radius of the second gear wheel $R_2$, mm</td>
<td>100</td>
</tr>
<tr>
<td>Radius of the third gear wheel $R_3$, mm</td>
<td>70</td>
</tr>
<tr>
<td>Radius of the fourth gear wheel $R_4$, mm</td>
<td>150</td>
</tr>
<tr>
<td>Weight of the first gear wheel $R_1$, kg</td>
<td>2</td>
</tr>
<tr>
<td>Weight of the second gear wheel $R_2$, kg</td>
<td>4</td>
</tr>
<tr>
<td>Weight of the third gear wheel $R_3$, kg</td>
<td>2</td>
</tr>
<tr>
<td>Weight of the fourth gear wheel $R_4$, kg</td>
<td>5</td>
</tr>
<tr>
<td>Number and diameter of the holes in the hydraulic piston, units x mm</td>
<td>4×5</td>
</tr>
<tr>
<td>Diameter of the hydraulic piston, mm</td>
<td>150</td>
</tr>
<tr>
<td>Diameter of the hydraulic piston rod, mm</td>
<td>10</td>
</tr>
</tbody>
</table>

The car collided with a very rigid barrier after the first 0.05 seconds. The speed decreased to 0 km/h (Figure 2), the car moved forward 0.4 meters (Figure 3). The maximum acceleration 17400 m/s$^2$ was obtained during the impact, which lasted only 0.2 ms (Figure 4). In such a short period of time, although at high acceleration, the human body was not able to react at such a load. Probable, that the driver or passengers were not seriously injured.

Fig. 2. Vehicle velocity, m/s, when the vehicle with the energy absorbing device hits an obstacle at the speed of 60 km/h.

Fig. 3. Vehicle displacement, m, when the vehicle with the energy absorbing device hits an obstacle at the speed of 60 km/h.
During that time the energy absorbing hydro pneumatic mechanical device gained momentum and kinetic energy of the car was converted to the kinetic and potential energy of energy absorbing hydro pneumatic mechanical device. After this, the car moved back from the rigid barrier reaching the short-term speed of 12 m/s (Figure 2).

In the figure 5 is shown alteration of kinetic energy of the car. The volume of kinetic energy was 0.14 MJ at the moment of collision with a barrier. 0.07 MJ of kinetic energy of the car was lost after 0.1 s, then the car had contact with the barrier. The energy absorbing hydro pneumatic mechanical device absorbed 50 percents of the car’s kinetic energy (Figure 5).

The subsequent calculations and the developed application will be used to analyze the device and determine the most effective energy absorbing forms and optimal parameters of the device elements.

The analyzed device is designed to absorb vehicle collision energy, therefore optimal parameters have to be set so as to suppress maximum kinetic energy in the shortest possible time on the vehicle’s collision with an obstacle. Meanwhile, the vehicle’s displacement has to remain minimal.

6. Conclusions

1. The present work has proposed a hydro pneumatic mechanical device designed to inhibit motor vehicle’s energy on a collision with an obstacle.
2. On the first contact with the obstacle the peak load is sustained by the hydraulic cylinder, where the vehicle's kinetic energy is transformed into potential energy of the hydraulic fluid in the cylinder.
3. During the subsequent stages of the collision, the vehicle’s kinetic energy is transformed into kinetic energy of the mechanical part of the device and potential energy of the pneumatic cylinder.
4. The energy absorbing hydro pneumatic mechanical device absorbs 50 percents of the car’s kinetic energy during 0.1 s, if the car’s speed is 60 km/h and others energy absorbing hydro pneumatic mechanical device parameters are shown in the table.
5. To obtain the best performance of the described device, parameters of individual elements of the device have to be set to optimum values.

References


