



VERIFICATION OF THE EMERGENCY BODY LIFTING SYSTEM BASED ON PNEUMATIC SUSPENSION

Mykola MYKHALEVYCH , Oleksandr YARYTA , Vladyslav SHAPOVALENKO * ,
Evgeny DON

Department of Automobiles, Kharkiv National Automobile and Highway University, Ukraine

* Corresponding author, e-mail: vladislav-shapovalenko@ukr.net

Abstract

Car accidents are the leading cause of death, with 1.2 million deaths each year, despite improvements in car safety, and forecasts indicate that road traffic fatalities will increase significantly by 2030 due to the increasing number of cars. This trend requires increased passive safety in car design. During independent crash tests that test the side safety of the driver and passengers, the impact energy is distributed and absorbed by the side sills, door pillars and safety bars located inside the doors. Unfortunately, there are no crash tests between cars of different mass and dimensions, for example, when a passenger car is hit from the side by an SUV. The main problem is that the height of the crossbar with crash boxes in an SUV is higher than the safety bars in the doors of a passenger car. Thus, it is difficult to predict the distribution of kinetic energy of the impact and the degree of injury to the driver and passengers of a passenger vehicle. A study of experimental emergency body lifting systems based on an electro-mechanical system and a hydropneumatic system at the moment of a side impact has been conducted. Such a system allows for 0.5 seconds to raise the car body to a height of 85 millimeters relative to the zero position and reduce injuries by 50% on the side where the side impact will occur. Using mathematical modeling, the functioning of the system and the possibility of implementing an emergency body lifting system based on a pneumatic suspension system were analyzed.

Keywords: pneumatic spring, passive safety, car suspension, vehicle body, air pressure, side impact

1. INTRODUCTION

Every year, the number of vehicles sold in the world increases [1-2]. This trend leads to an increase in road accidents [3-5]. The most dangerous type of collision between two vehicles is a side impact, the average statistical indicator is 24% in different regions of the world [6-8]. The driver and passengers receive the greatest injuries during a side impact due to the minimum deformation zone, which is not enough to absorb the maximum amount of impact energy and reduce injuries to the driver and passenger [9]. Independent organizations that study vehicle safety have developed and are improving side impact research methods every year to better analyze potential side-impact accidents, research programs may vary depending on the organization that is involved in the research. Usually, dummies are used for research, which allows each specific car to be evaluated for safety with high accuracy without taking into account the average injury values. For each specific case, injury coefficients for different parts of the body in a side impact are calculated in order to further make an objective assessment of the safety of the car.

Car manufacturers are trying to find different approaches to reduce driver and passenger injuries. In contrast to classic approaches such as: safety bars in car doors, side airbags, safety trim for car doors, etc.. At the moment, there are two such passive safety systems of pre-activation, which, according to car manufacturers, are able to reduce injuries to the driver and passengers in the chest and abdomen area during a side impact by 50% [10-11]. The use of such systems in the near future will improve passive safety and reduce injuries to the driver and passenger during a side impact.

2. ELECTROMECHANICAL SYSTEM OF EMERGENCY LIFTING OF THE CAR BODY

The conceptual electromechanical suspension system can increase or decrease the load on each wheel separately, this is necessary in order to adapt to the road as needed, by changing the settings of the electronically controlled shock absorbers. This means that the system can actively control the position of the car body while driving. In addition to smoothness of movement, reducing body roll, it has

a very important advantage in terms of passive safety.

Such a suspension system allows you to additionally use its functionality to ensure the possibility of implementing the function of emergency body lifting in the event of a side impact by lifting the body from the side of danger.

For such a system to function, additional elements must be used that allow monitoring the situation on the right and left sides of the car in order to perform an emergency body lift in time.

To do this, the emergency body lift system uses information coming from radar sensors located on the sides of the car in the front bumper and records movement at a distance of up to 50 meters and checks the situation on the right and left sides of the car at a frequency of 15 times per second. The control unit, processing the information, determines the potential risk from a vehicle approaching from the side, calculates the minimum permissible distance at which the system can be triggered and the expected time to a collision. The system allows to detect the threat of a side collision at speeds from 25 km/h to 60 km/h. In such a situation, the electromechanical system must raise the car in 0.5 seconds to a height of 85 mm in the event of a collision from the side from which the critical approach of the car occurs (Fig. 1) [11].

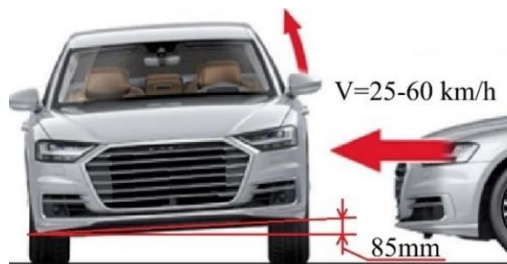


Fig. 1. Activation of the electromechanical system of emergency lifting of the car body [11]

For the emergency body lift function to be activated, the vehicle must be moving at a speed above 8 km/h [12].

Near each wheel are compact actuators 1 that operate from the 48-volt main electrical system of the vehicle.

The main components of the 48-volt electrical system are a belt-driven starter-generator and a lithium-ion battery. The belt-driven starter-generator is the power source for the 48-volt electrical system. If it works as a starter, it should be considered an energy consumer within the 48-volt system. The voltage converter is the connecting link between the 48-volt electrical system and the 12-volt electrical system. The torque from the actuator 1, which is bolted to the bottom of the vehicle (mounted on the body) together with the front and rear axle struts, increases the torque to 1100 Nm via the belt drive 2 and ensures its transmission to the wave gearbox 3, inside which is located a steel torsion bar 4. Which can rotate by an angle of 20 degrees. Due to the rotary movement of the lever 5 fixed on the side of

the wave gearbox, the force component acts on the corresponding damper lever or the corresponding transverse rod through the corresponding connecting rod, which transmits the force through the hinged connection to the rod 6, which is connected at its upper end to the air spring housing.

As a result, the distance between the wheel and the car body decreases or increases depending on the direction of rotation of the drive (the springs move up or down).

The drive is supported on the wheel contact point by means of a lever, a connecting rod, a damper lever and a transverse link. The rotary movement of the lever raises the drive and the vehicle body directly connected to it. The damper piston rod is tensioned (rebound damping). If the lever is turned in the opposite direction, the vehicle body is lowered. The suspension strut is compressed and the damper piston rod is loaded (compression damping).

The motor is activated by an alternating voltage of 0 to 48 volts with a phase rotation of 120°. This generates currents in the stator windings in alternating directions. Corresponding magnetic fields are generated around the coils through which the current flows. Their polarity changes each time the direction of the current changes. This generates a magnetic field with rotating polarities that surrounds the rotor. This magnetic field exerts a corresponding force on the permanent magnets that are permanently connected to the rotor, thereby generating a torque that causes the rotor to rotate. Depending on the activation (direction of rotation of the magnetic field), clockwise or counterclockwise rotation can be achieved.

The position of the rotor is determined by a sensor. This sensor is located at the end of the rotor, at the opposite end from the belt pulley. There is a permanent magnet in the hollow rotor shaft. Its position is measured by a magnetoresistive sensor. The principle of magnetoresistive measurement is based on the fact that the electrical resistance in ferromagnetic metals changes under the influence of external magnetic fields. Analysis of the changes in resistance allows the position of the magnet on the rotor shaft, and therefore the angle of the rotor, to be determined.

The design of this emergency body lifting system is not unified, but is designed for a specific car model.

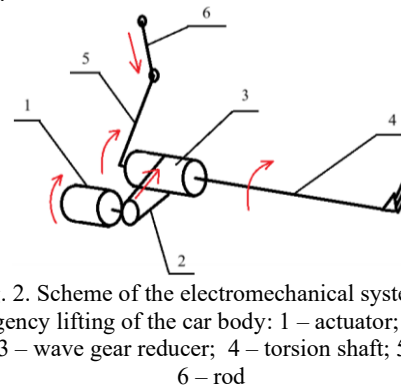


Fig. 2. Scheme of the electromechanical system of emergency lifting of the car body: 1 – actuator; 2 – belt drive; 3 – wave gear reducer; 4 – torsion shaft; 5 – lever; 6 – rod

In the front suspension, the force acts on the lower part of the air spring housing, and in the rear suspension on the transverse link [11-12].

As a result of the collision, the impact energy will be directed to the side sills and the floor structure. The load on the passengers is reduced by 50% compared to a side impact without an electromechanical emergency body lift system. The design of this emergency body lifting system is not unified, but is designed for a specific car model.

3. ELECTROHYDRAULIC SYSTEM OF EMERGENCY LIFTING OF THE CAR BODY

Active hydraulic suspension, has the ability to influence the passive safety of the driver and passengers by reducing injuries in the event of a side impact, this conceptual safety system allows you to influence the safety of the driver and passengers of the car during a side impact. In the event of a side impact, the electro-hydraulic suspension system raises the body to a height of 80 millimeters (Fig. 3). The time for which the system is activated is not disclosed by the manufacturer.

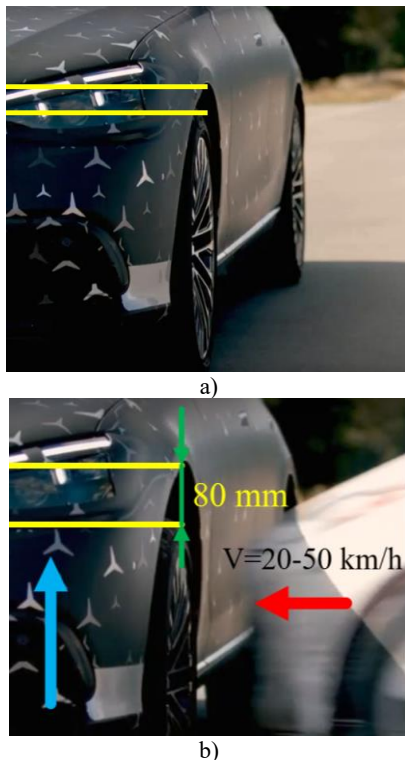


Fig. 3. Activation of the electrohydraulic system of emergency lifting of the car body [13]: a – body position before the emergency body lift system is activated; b – body position after detecting the risk of a side impact

In this case, the impact force is directed to the lower side of the car, and not to the door itself. The system consists of radar sensors located in the front of the car in the bumper. They detect the risk of a side impact. After detecting the risk, the electronic control unit transmits a signal via the CAN

(Controller Area Network) connection to the electronic control unit 1 (Fig. 4).

Which is combined in one housing 3 with the electric motor 2, such a compact design made it possible to place the hydraulic pump 5 in one housing. Depending on the signal, the hydraulic pump can change the damping coefficient using two channels, each of which has pressure sensors 4 that allow for accurate monitoring pressure change in the hydraulic part of the emergency lifting system of the car body. The working fluid under pressure enters through the valve 6 and the adjustable throttle with a check valve 7 into the working cavity under the rod 8, with an increase in pressure, the shock absorber rod 10 rises and changes the volume of the pneumatic spring 11. From the cavities 9 located above the rod, in the opposite direction the pressure will decrease and through the adjustable throttle 12 with a check valve and the valve 13 will flow through the pump 5 to the working cavity under the rod. As soon as the control unit receives a signal from the radar sensors that there is no danger, the system redistributes the pressure between the working cavities under the rod and above it, returning the suspension to the transport position based on information from four body level sensors.

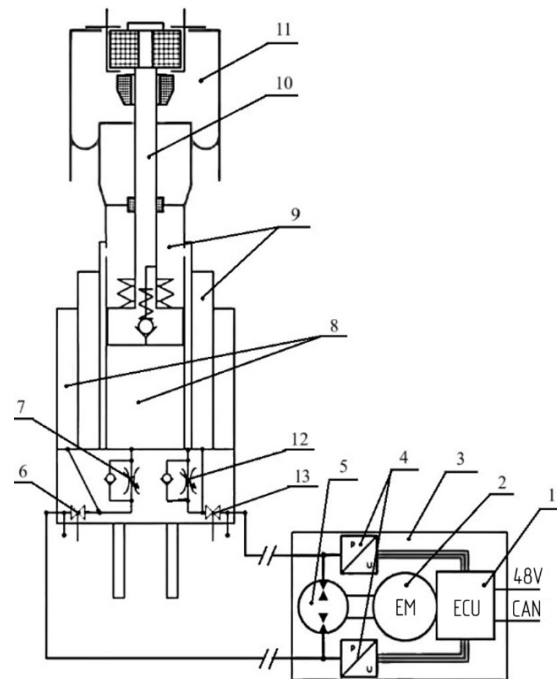


Fig. 4. Scheme of electrohydraulic system of emergency lifting of the car body: 1 – control unit; 2 – synchronous electric motor; 3 – electrohydraulic pump; 4 – pressure sensors; 5 – hydraulic pump; 6 – tap of the working cavity under the stem; 7 – adjustable throttle with check valve of the working cavity under the rod; 8 – working cavity under the rod; 9 – working cavity above the rod; 10 – shock absorber rod; 11 – working cavity of the air spring; 12 – working cavity tap above the rod; 13 – adjustable throttle with check valve of the working cavity above the rod

Similar to the previous system, the main function in this case is to reduce the impact energy that affects

the driver and passengers in a side impact. The system with the emergency body lift function helps reduce the impact force by 50% and ensure minimal load on the chest and pelvic-femoral part of the driver or passengers [14 15].

4. ANALYSIS OF EMERGENCY BODY LIFTING USING A POSITION TRACKING ALGORITHM

In order to check the reliability of the values that characterize the operation of the electromechanical and electrohydraulic emergency body lifting systems, we will use the Tracker analysis tool. [16] (Fig. 5). The program allows you to model and analyze the movement of objects in video or images. We will use the ability to manually track the movement of objects with the overlay of position, velocity, and acceleration data.

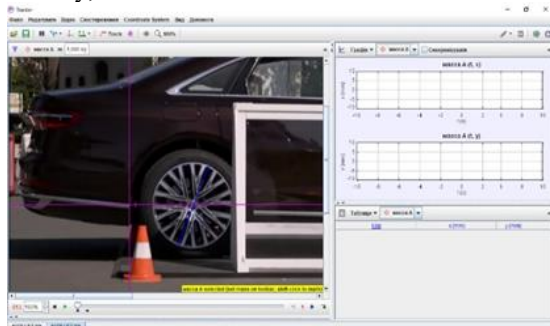


Fig. 5. Tracker app interface

We will use available video fragments of the operation of electromechanical and electrohydraulic emergency body lifting systems, which allow us to visually obtain information about the movement of elements selected as a reference point from the initial (zero) location of the car body to the highest position after the operation of the external lifting system. (Fig. 6-7).

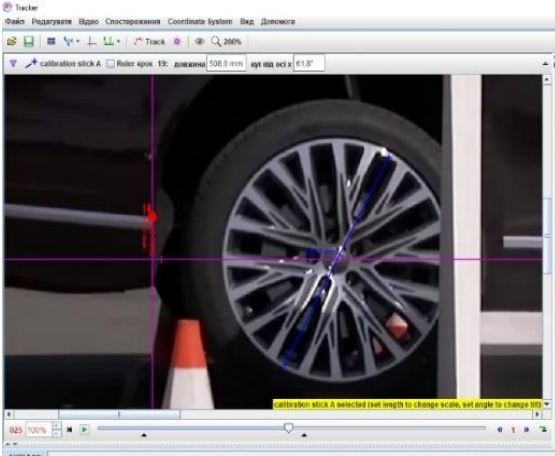


Fig. 6. A frame of video material of the operation electromechanical emergency body lifting systems

After analyzing the data on the operation of the electromechanical and electrohydraulic emergency body lifting systems, which were obtained using the Tracker program (Fig. 8), a graph was constructed of

the dependence of the vertical movement of the car body on the time of operation of the emergency body lifting system.

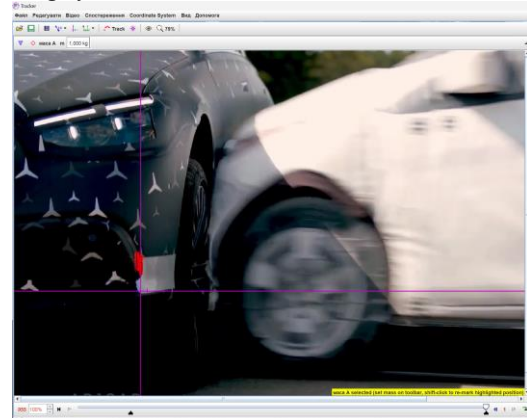


Fig. 7. A frame of video material of the operation electrohydraulic emergency body lifting systems

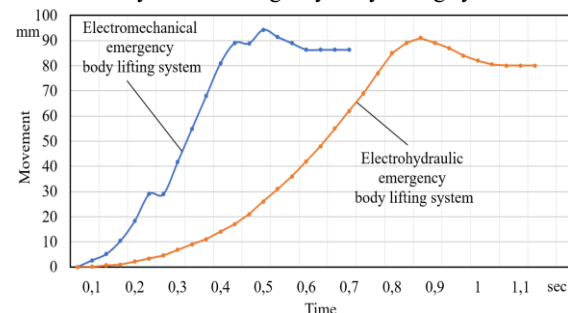


Fig. 8. Verification of the operation of emergency body lifting systems

The operation graph of the experimental electromechanical emergency body lifting system (blue graph), which is based on the electro-mechanical part of the transverse roll stabilizer, showed that in 0.5 seconds the system is able to raise the body to a height of 95 millimeters and subsequently stabilizes at a height of 85 millimeters, which corresponds to the information stated in the media. In comparison with the experimental electrohydraulic emergency body lifting systems which is based on the pneumatic-hydraulic suspension system of the car showed the body lifting time in 0.8 seconds to a height of 90 millimeters after stabilization the height is 80 millimeters. The operating time of these two different actuators coincides with the declared one, only the systems differ in the approach to building the emergency body lifting system.

5. STUDY OF THE POSSIBILITY OF USING A PNEUMATIC SYSTEM AS AN EMERGENCY BODY LIFTING SYSTEM

To investigate the possibility of using a pneumatic suspension system in the event of an emergency body lift, a mathematical model needs to be created.

The complexity of mathematical models depends on the purpose of such models. To implement a model to study the function of emergency body

lifting and analyze the speed of operation of elements responsible for the operation of the system, first you need to draw up a calculation diagram of the car suspension system. (Fig. 9) in which 1 is the sprung mass of the vehicle and 2 is the unsprung mass of the vehicle. Also, for this scheme, it is necessary to display the elastic and damping elements of the suspension, since they are mandatory for a reliable assessment of the time and height of raising the vehicle body.

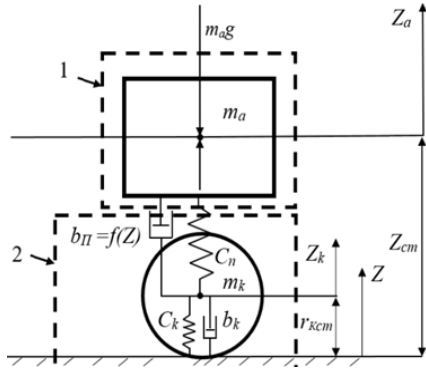


Fig. 9. Calculation diagram of the vehicle suspension system

The presented calculation scheme makes it possible to evaluate the relationships between the suspension elements of a car and to compile a system of equations for further mathematical modeling.

$$\begin{cases} m_k \cdot j_a = -m_k \cdot g - \left[F_s - \theta_n \cdot (\dot{Z}_a - \dot{Z}_k) \right] + C_k \cdot (r_k - Z_k) - \theta_k \cdot \dot{Z}_k \\ m j_a = -m \cdot g + F_s - \theta_n \cdot (\dot{Z}_a - \dot{Z}_k) \\ Z_{k_0} = r_{kcm} \\ Z_{a_0} = Z_{cm} \end{cases} \quad (1)$$

$$\begin{cases} \frac{d \cdot p_b}{dt} = \frac{k \cdot R \cdot \text{sign}(p_1 - p_b) \cdot W(T_1; T_b) \cdot G_b - p_b \cdot \frac{dV_b}{dt} - \frac{dQ_b}{dt}}{V_b} \\ V_b = V_b(h_b; h_b) \\ h_b = Z_a - Z_k \\ \frac{dQ_b}{dt} = \frac{\alpha_0 \cdot (k-1)}{R} \cdot F_b \cdot \left(\frac{T_{st}}{T_b} \right) \\ \frac{dT_b}{dt} = \frac{T_b}{V_b} \cdot \frac{dV_b}{dt} + \frac{T_b}{P_b} \cdot \frac{dp_b}{dt} - \frac{T_b \cdot R \cdot W(T_1; T_b) \cdot G_b \cdot \text{sign}(p_1 - p_b)}{V_b \cdot p_b} \\ F_s = P_b \cdot S_b \\ S_b = f(h_b) \end{cases} \quad (2)$$

where:

m_k – wheel weight;

j_a – acceleration of the body during the action of vertical displacement;

g – acceleration of free fall, $g = 9,81 \text{ m/sec}^2$;

F_s – force in a pneumatic cylinder;

θ_n – shock absorber damping coefficient;

$\dot{Z}_a$ – derivative of the vertical coordinate of the vehicle body position;

$\dot{Z}_k$ – derivative of the vertical coordinate of the vehicle wheel position;

C_k – wheel stiffness coefficient;

r_k – wheel rolling radius;

θ_k – wheel damping coefficient;

C_n – suspension stiffness coefficient, $C_n = \frac{F_s}{h_b}$;

Z_{cm} – vertical coordinate of the static position of the vehicle body relative to the supporting surface;

Z_k – vertical coordinate of the movement of the vehicle wheel center;

Z_a – vertical coordinate of the cylinder attachment point;

Z_k – vertical coordinate of the wheel position;

Z_{k_0} – vertical coordinate of the wheel position at rest;

r_{kcm} – static radius of the vehicle wheel;

Z_{a_0} – vertical coordinate of the body position at rest;

k – adiabatic index;

R – universal gas constant;

T_1 – temperature before entering the pneumatic cylinder;

G_b – air consumption when filling and emptying a pneumatic cylinder;

T_b – air temperature in a pneumatic cylinder;

V_b – volume of the pneumatic cylinder;

p_b – air pressure in a pneumatic cylinder;

p_1 – air pressure in the pipeline before the pneumatic cylinder, to the electromagnetic control valve;

S_b – area of the pneumatic cylinder;

h_b – height of the pneumatic cylinder;

Modeling of the working process in the pneumatic circuit of the suspension system of a wheeled vehicle is performed for the case when the vehicle is stationary, there are no oscillations from external disturbances; the duration of the transient process does not exceed 10 seconds, therefore heat transfer with the environment occurs without taking into account the heat capacity of the walls of the pneumatic cylinder shell; an ideal gas is used as the working fluid.

The emergency body lift function is simulated on a stationary vehicle. In this case, the calculation scheme for modeling the process of changing the position of the vehicle body relative to the support surface can be represented as an oscillatory system that contains an elastic element - an air spring of the vehicle suspension with a nonlinear elastic characteristic and a hydraulic damping device (shock absorber). Since the mass of the unsprung parts of the vehicle is usually no more than 15...20% of the sprung mass, and the stiffness of the suspension is several times less than the stiffness of the tires and the frequency of random oscillations of the unsprung

mass is much greater than that of the sprung mass, the influence of the unsprung mass on the movement of the body in this case can be neglected.

The working process in the pneumatic circuit of the vehicle suspension system occurs as a result of the control effects from the control system, and in turn, causes changes in the position of the vehicle body relative to the supporting surface. Only the natural damped oscillations of the part of the sprung mass of the vehicle that falls on one elastic element of the suspension system are taken into account. Kinematic connections in such a system allow only rectilinear vertical movements.

In this case, the oscillatory system with one elastic element of the vehicle suspension system can be represented as a system with one degree of freedom and part of the general calculation scheme for its mathematical modeling can be simplified. This allows the following assumptions to be applied: forced oscillations of the vehicle from force or kinematic disturbances are absent; oscillatory motion of the unsprung mass is not simulated; the effect of dry and intermolecular friction in the vehicle suspension parts is not taken into account; there is no connection between the oscillations of the front and rear parts of the vehicle body. The steady-state equation of such a system has the form [17-25]:

$$M \cdot \left(\frac{dH}{dt} \right)^2 + M \cdot g = b_a \cdot \frac{dH}{dt} + p_o \cdot S_a(H) \quad (3)$$

where:

M – part of the sprung mass of a vehicle that falls on one elastic element of the suspension system, kg;

H – current distance of the vehicle body from the supporting surface, m;

t – current time of the process of changing the position of the wheeled vehicle body, sec;

g – free fall acceleration, m/sec²;

b_a – hydraulic resistance coefficient of the shock absorber, H·sec/m;

p_o – current pressure in the air cylinder, Pa;

$S_a(H)$ – active (effective) area of the air cylinder, m².

The system equation briefly reflects the process of filling and emptying the variable open internal volume of the pneumatic cylinder cavity. Each DE-link, which is characterized by the corresponding pressure and temperature, is assigned indices that correspond to the calculated capacities. These also include the volumes of pipelines connecting the receiver with the control system actuator, and the actuator with the pneumatic cylinder. In the connection of each pipeline with the consumer (device), there is a local hydraulic resistance, which is characterized by the effective area.

In the pipeline between the actuator and the pneumatic cylinder, air moves both from the actuator to the pneumatic cylinder and in the opposite direction. The force of the pneumatic cylinder is determined based on the filling dynamics, it is a function of the active pressure area of the pneumatic cylinder. In this case, the pressure in the pneumatic

cylinder can monotonically increase and monotonically decrease. In the pipeline between the receiver and the actuator, air moves only in one direction - from the receiver to the actuator. V, p, T – volume, pressure and temperature of the air corresponding differentiating link; μ, f – flow rate and effective area of the corresponding differentiating link.

To implement the algorithm, Simulink, a graphical programming environment based on MATLAB for modeling, simulation, and analysis of multi-domain dynamic systems, was used. A structural and logical diagram of an emergency vehicle body lift was constructed. (Fig. 10). Before starting the simulation, the parameters inherent to the vehicle were formed, which was previously studied in the program Tracker. Among such parameters is the mass of the vehicle 500 kg, wheel weight 18 kg, static wheel radius 0,28, dynamic wheel radius 0,25, wheel and spring stiffness and wheel and spring damping coefficient 0,2.

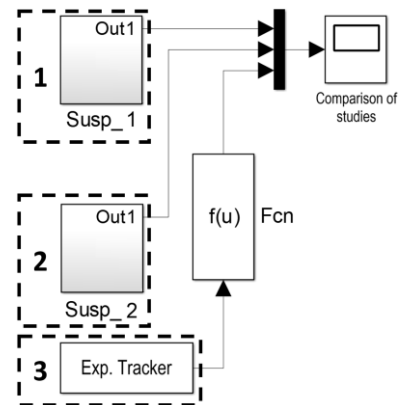


Fig. 10. Structurally logical diagram of the emergency vehicle body lifting system: 1 – algorithm for standard settings of the vehicle's pneumatic suspension system; 2 – algorithm with changed parameters of the shock absorber of the pneumatic suspension system of the vehicle; 3 – parameters transferred from the study of emergency body lifting by the program Tracker

The speed of the body lifting based on the air suspension system with the characteristics of a passenger vehicle was investigated, as well as how the shock absorber damping settings affect the speed of operation. The result is presented in the form of graphs (Fig. 11), which allow comparing three different options for the emergency body lifting system operation.

Graph 1 (Fig. 11) corresponds to subsystem 1 (Fig. 10) where the damping and filling settings of the air spring are made in the standard operation mode of the vehicle's pneumatic suspension system, as can be seen in the graph 1, this occurs slowly over 0,8 sec and does not allow the body to be lifted 85 mm in 0,5 sec, which does not correspond to the parameters obtained during the verification of the operation of the electro-mechanical emergency body lifting system in the Tracker program. The graph 2 (Fig. 11) subsystem corresponds 2 (Fig. 10) already with changed parameters shows that using the

pneumatic system and settings it is possible to obtain the possibility of emergency lifting of the body for 0,5 sec. Graph 3 (Fig. 11) corresponds to the electromechanical emergency body lift system, the operation of which was verified in the Tracker program. This system allows the car body to be raised by 85 mm in 0.5 seconds before a possible side impact.

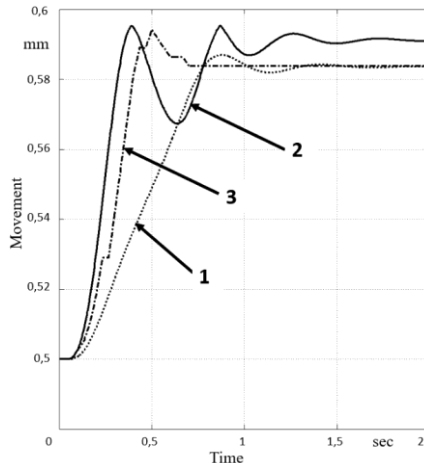


Fig. 11. Body lifting speed: 1 – standard settings of the vehicle's air suspension system; 2 – changed parameters of the shock absorber of the vehicle's air suspension system; 3 – parameters transferred from the study by the program Tracker

6. CONCLUSIONS

While researching passive safety systems, the question arose of the possibility of combining vehicle systems that allow for further improvement of the passive safety properties of the driver and passenger inside the vehicle during a collision. One such example is the emergency body lift system, which is based on electromechanical components installed in the vehicle's suspension. This system allows, in the unlikely event of a side impact when the speed of the approaching vehicle is in the range from 25 km/h to 60 km/h, to lift the vehicle body by 85 millimeters in 0.5 seconds, thereby exposing the lower part of the vehicle, where the reinforced side sills and safety bars are located, to a side impact, which allows for a 50% reduction in injuries to the driver and passengers. Taking into account the features of the emergency body lifting system, a study was conducted on the possibility of functioning based on the vehicle's pneumatic suspension system. The studies showed that by changing the settings of the damping parameters of the shock absorbers and the pneumatic suspension system, it is possible to obtain the parameters of the emergency body lifting system to operate by 85 millimeters in 0.5 seconds.. This makes it possible to use and unify an emergency body lifting system based on a pneumatic suspension system for vehicles equipped with a suspension with pneumatic elements. This topic is relevant against the backdrop of the trend of increasing accidents

and the increase in the number of vehicles in the world.

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**D.Sc. Mykola**

MYKHALEVYCH, Professor Department of Automobiles, Kharkiv National Automobile and Highway University. He defended his PhD thesis in 2009. In 2021, he received the degree of Doctor of Technical Sciences. Scientific direction he is working on: Improvement of electropneumatic devices - brake drive; - transmission control devices; - air suspension control devices. Chassis and control systems of high-speed cars. Modeling of vehicle dynamics and work processes. Research of control system elements in a wide range of ambient temperatures.

e-mail: mkolyag@gmail.com

**C.Sc. Oleksandr YARYTA**

Department of Automobiles, Kharkiv National Automobile and Highway University. In 2017, he received the degree of Candidate of Technical Sciences. The scientific direction he is working on: Improvement of electropneumatic transmission devices. 3D modeling.

e-mail: aleks.yarita@gmail.com

**Vladyslav SHAPOVALENKO**,

assistant Department of Automobiles, Kharkiv National Automobile and Highway University. Scientific direction he works on: research and improvement of passive safety systems.

e-mail: vladyslav-shapovalenko@ukr.net



C.Sc. Evgeny DON Department of Automobiles, Kharkiv National Automobile and Highway University. In 2020, he received the degree of Candidate of Technical Sciences. The scientific direction he is working on is:

Improvement of dynamic properties of electropneumatic brake control of a wheeled vehicle.e-mail:

evgenypj82@gmail.com