Clearance control of vehicle with hydropneumatic suspension and the wheel formula 8x8

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Abstract. In the present work the problem of controlling the elements of a hydropneumatic suspension of a multi-axle vehicle is considered. Control algorithms are proposed that provide the required law of clearance change in various conditions. A computer simulation was carried out, which showed the correctness of the work of the presented algorithms.

Introduction
One of the main requirements for high-speed vehicles is a high average speed on the ground. This speed depends on many factors, including the efficiency of the suspension system. In case of insufficiently effective operation of the suspension system, the driver is forced to reduce the speed of the vehicle due to overload or fatigue. Thus, the improvement of vehicle suspension systems can be considered a very important task [1].

Depending on the operating conditions and requirements for the vehicle, various suspension systems can be used. One of the possible variants of such systems is a hydropneumatic suspension (HPS), the main advantages of which are high smoothness, the ability to adjust the position of the vehicle body relative to the road surface, effective reduction of vibrations, adaptation to the driving style of a particular person [2, 3].

In modern vehicles the main units are controlled by an onboard information control system, one of the main elements of which is an electronic suspension control unit. Software development for electronic suspension control unit is one of the most important stages of design, since it determines the main characteristics of the vehicle and its compliance with technical requirements.

The main results in the design and implementation of algorithms and control systems for HPS are currently obtained for cases of two-axis and three-axis vehicles (these types of vehicles are most often used in practice). However in some cases there is a need for the development of the control system for HPS for multi-axle vehicles intended for the transportation of non-standard cargoes in non-standard operating conditions. Hydraulic circuits of such vehicles are usually characterized by the absence of diagonal connections to control any wheel in case of main line breakdown, and the number of HPS’s functions is minimized to ensure the greatest simplicity, reliability and maintainability.

The purpose of this work is to create algorithms for controlling HPS of a vehicle with a wheel formula 8x8, ensuring the process of uniform raising and lowering of the platform when changing the clearance and leveling, as well as the correct process of hanging the wheel (“jack” mode). In the
process, computer simulation methods were used, and the results were verified by testing the “Model-in-the-Loop” (MiL) and “Hardware-in-the-Loop” (HiL).

1. Clearance control algorithms
Changing the clearance is effected by moving the rod up or down for one or more hydropneumatic springs. Based on the technical requirements, the following functions should be implemented in the algorithms:

- setting the clearance value;
- leveling of the vehicle body within the working area of the suspension travel;
- hanging of individual wheels.

The input signals for the control algorithms embedded in the electronic suspension control unit will be wheel movements, roll and trim values of the vehicle body. The wheel position sensors are designed to determine the current value of the clearance and are included in the feedback circuit of the control loop for changing the clearance of each hydropneumatic spring. The readings of the roll and trim angle sensors are used for the leveling.

The executive elements used to change the clearance are:

- one-way hydraulic control valves for injection and discharge from the cavities of the hydropneumatic springs;
- one-way hydraulic control valves on suspension control units for injection and discharge from piston and rod cavities;
- proportional valves on suspension control units for injection and discharge from piston and rod cavities.

Structurally, vehicle is divided into 2 trolleys; each one is controlled by a single suspension control unit. On the front trolley wheels are located from 1 to 4, and on the back – from 5 to 8, respectively.

To implement the control algorithms, a deterministic finite state automaton was developed in the Stateflow environment of the MATLAB system. A generalized scheme of its states and transitions is presented in the figure 1.

![Figure 1. Generalized state machine scheme.](image)

The control process is carried out simultaneously for two trolleys. In each of them there is a choice between lifting and lowering the vehicle, with descent being of higher priority. The HPS control algorithms were implemented in the MATLAB / Simulink system using a model-based approach. An example of the implementation of the lifting function using the Stateflow tool is shown in figure 2, an example of the controller structure is shown in figure 3.
The increase or decrease in clearance is achieved by injecting or discharging the working fluid from the piston / rod cavity of hydropneumatic springs due to the coordinated operation of one-way control valves and proportional valves on the suspension control unit. Opening / closing of the hydraulic locks occurs when the specified height of the rack is reached. Similarly the vehicle body leveling and wheel hanging are realized.

For uniform descent and lifting of the vehicle PI-regulators are used which determine the duty cycle of the PWM signal for opening proportional valves.

![Implementation of finite state automaton for lifting function.](image)

**Figure 2.** Implementation of finite state automaton for lifting function.

![Controller structure for lowering and lifting.](image)

**Figure 3.** Controller structure for lowering and lifting.

### 2. Algorithm testing

Verification of the developed clearance control algorithms took place in two stages. At the first stage, MiL-testing was carried out, in which the control system model was integrated with the vehicle model in Simulink. In this case, the output signals of the first model and the input signals of the second model were the control signals coming to the valves. In this model, it is possible to track the
correctness of the algorithms of lifting and lowering the vehicle without feedback (i.e., without position sensors), as well as to estimate the change in pressure in the rod and piston.

At the second stage, the control algorithms were tested by HiL-testing. From the developed model in Simulink was generated code in C. Then the code was loaded into the rapid prototyping unit, replacing the real electronic control unit in the process of the control system debugging. The input signals for this model were the position sensor readings coming from the CAN bus, and the output signals were the control signals coming to the valves. For example, figure 4 shows graphs of changes in output values with an increase in clearance from 300 mm to 700 mm.

Figure 4. Readings of the position sensors with a step-like increase in clearance.

3. Conclusions
In the course of the work, the control algorithms for the hydropneumatic suspension were formulated and their software implementation in the Simulink environment was proposed. The conducted two-stage verification allowed to draw a conclusion about the correctness of their work: all algorithms ensure the fulfillment of the stated requirements; the vehicle platform rises and descends evenly (the readings of the position sensors are close to each other, which means no distortions).

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