Simulation modeling of the automobile braking system performance

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Abstract. Simulation model of the automobile braking system performance taking into account not only the wheel, brake pads, brake drum dynamics but the dynamics of the hydraulic brake system: the main hydraulic cylinder, the brake gear hydraulic cylinders has been presented. Effect of changing parameters of the braking system elements on the braking distance of the automobile has been considered. Road users’ safety relies heavily on effectiveness of vehicle braking system. Thus, braking system design is essential when designing a new vehicle. Modeling of the functionality of the designed system is one of the most important phases of design. Time and material expenses for imitational modeling are always less than actually producing models and conducting experiments on them. Experiments should prove theoretical abstracts stated while modeling. Thus, the imitational model should be well designed and adequate. Imitational model allows efficient operation of brake system with different system of control.

1. Introduction

Safety of travelers depends on effectiveness of performance of the automobile braking system. Thus, especial attention at designing a new automobile is paid to development of the braking system. One of its major stages is simulation of performance of the synthesized braking system and its automatic control system. Material and time expenditures on simulation modeling are always less than on making prototypes and trial models to conduct full-scale experiments. Experiments with the trial model are to prove theoretical conclusions made in the course of simulation completely. Therefore, the simulation model is to have a high degree of adequacy and high accuracy.

At simulation of the car braking system it is necessary to synthesize interconnection of different physical elements and systems – linear and rotation motion of mechanical parts, operation of the hydraulic system with regard to the braking fluid properties, electric control circuits with automatic control system based on a microcontroller in the same simulation model. Such simulation model with high accuracy and speed of the simulation experiment proceeding can be synthesized by means of MatLab. The developer can also optimize functioning of the braking system performance algorithm, optimization of parameters of the braking system elements and use the simulation model as a control system to detect disturbances at operation of automatic control system on a real object in a simulation model made in MatLab. The purpose of the work is minimization of material and time expenditures on...
the braking system development due to the braking system simulation modeling, conducting simulation experiments for optimization of algorithm of functioning of the braking system automatic system control and parameters of elements of the developed braking system.

In the work there have been represented a simulation model of performance of the braking system in different modes. It demonstrates dynamics of motion of all mechanical parts of the braking system – hydraulic cylinders, pads, wheels and visualizes the operation of algorithm of the braking system performance. After optimization of the control system parameters the simulation model allows to switch to the board with the mechanical part of the braking system and check the control system operation effectiveness. During the check the observing system conducts estimation of external and internal disturbances for more effective performance of the automobile braking system.

2. Publications analysis

Deceleration of a vehicle is a very complex process and of great importance for the traffic safety. This complexity originates from the occurrence of many events in different types of mechanical, electrical, thermal, pneumatic, etc. during braking. These operations occur in various points of the vehicles at varying densities and effect several parts of the mode of transport [1]. The mechanical energy of the vehicle is mostly transformed into thermal energy and spread to environment [2].

The automobile braking system consists of movable mechanical parts and the hydraulic system. Modern braking systems have a complex structure of interconnected elements [4]. The main elements of the system are: a vacuum booster, a main hydraulic cylinder, front and rear wheels brake gears (a hydraulic cylinder, pads, a brake disk, a brake drum), a pressure regulator valve, antilocking system, automatic control system [5]. At building up a simulation model it is necessary to take into account dynamics of the braking system elements and dynamics of the car movement depending on the braking system performance [6]. To ensure interconnection of elements belonging to different physical systems in one simulation model is possible in the Matlab/Simulink problem-solving environment [7]. In the suggested environment there can be realized a programmable system and obtained graphics of transients with high accuracy [10]. Matlab can also be used for controlling the braking system intelligence panel and perform follow-up control on the basis of the response discrepancy of the panel and simulation model to control actions. This allows to detect external and internal disturbances affecting the real braking system of the automobile and to develop a control algorithm for their compensation [11].

3. Purpose and statement of problem

The purpose of the work is to increase effectiveness of the process of the braking system synthesis by means of development of simulation model of performance of the braking system and its elements and conducting of simulation experiments for determining the optimal algorithm of operation of the braking system control. To achieve the purpose it is necessary to solve the following tasks:

- analysis of functioning of the braking system elements;
- development of the simulation model structure;
- synthesis of the simulation model of the braking system performance;
- optimization of the regulator parameters and of the operation algorithm.

For realization of the set tasks it is necessary to describe dynamics of the mechanical elements motion with the help of transfer functions and use specialized libraries Matlab/Simulink for building up the hydraulic part of the braking system.

4. Simulation model

A general view of the simulation model of the automobile braking system is represented in Figure 1.
To simulate functioning of the model it is necessary to specify parameters of the braking system elements [12]. Parameters of each element of the braking system are introduced separately in a dialogue box of a correspondent subsystem. In dialogue boxes there presented short information about the required parameters as well as about the layout and dimensionality to be adhered when introducing parameters of the braking system elements. Information about geometrical parameters of each wheel and their weight is given for the subsystem simulating dynamics of the wheels rotation. For the subsystem describing the automobile dynamics it is necessary to specify the automobile weight and general resistance affecting it during the motion [12]. For the subsystem simulating the brake pads parameters denoting interrelation between a degree of a pad fitting and the moment of braking, which it causes, are to be specified. Parameters of hydraulic cylinders of the brake gears – geometry, changes of pressure, resistance of their rods are specified in specialized elements of the Simulink libraries. Parameters of conversion of the brake pedal travel into pressure of braking fluid in the braking system arising at shifting the main cylinder are specified in the subsystem of the vacuum booster. To register the load affecting the automobile rear axle in the subsystem simulating the pressure regulator of braking fluid in the rear brake gears a value of the axle load is specified, which results in pressure amplification in the rear axle braking circuit. In the subsystem simulating the internal combustion engine there specified a torsion torque and dynamics of its changing with regard to the clutch engagement/disenagement.

The simulation model demonstrates dynamics of all four automobile wheels rotation under the action of the engine torque and braking torque from the brake pads. The model allows estimating dynamics of the wheels rotation at braking operation both at the engaged and disengaged clutch. Calculation of the automobile braking distance is performed automatically, which enables estimating the braking system effectiveness at different speeds of the automobile.

Conducting simulation experiments with the help of a synthesized braking system simulation model significantly simplifies the task of the designer. He does not have to carry out full-scale experiments to determine the braking system effectiveness, which reduces material and time expenditures on its development. It also enables estimation of ineffective braking systems avoiding the car breakdown or accidents making its repairing impossible. The given simulation model allows the designer carrying out several experiments simultaneously as well as compare several braking system under development in the automated mode. Thus, the synthesized model ensures increasing effectiveness of designing the automobile braking system.

Figure 2 represents a graph of changes in the automobile speed: smooth acceleration of the car to the speed of more than forty kilometers per hour and in thirty seconds after starting acceleration the clutch being disengaged and the brake pedal depressed.
Figure 2. Changes in the automobile speed

The graph demonstrates a smooth loss of speed to a full stopping of the car. So it is possible to judge visually how hard the process of braking is and to adjust parameters of the braking system elements. At adjusting the simulation model allows to try out different braking modes: smooth braking without clutch disengaging and not up to the full stop of the automobile; smooth braking with clutch disengaging up to the full stop of the automobile; sudden emergency stop for a minimal time period.

Figure 3 represents a graph characterizing the function of the automobile movement.

Figure 3. Movement of the automobile
The automobile braking distance can be determined from the graph. In the developed simulation model, the braking distance is determined automatically and is displayed in meters on a digital indicator. In the automobile subsystem at specifying the road resistance the adherence of the tires with the road surface is taken into account. Thus, estimation of effectiveness of the braking system operation in different road conditions is performed.

The simulation model allows to estimate effectiveness of the braking system operation on many parameters: the automobile braking distance, smoothness of braking depending on the mode, regulation of pressure in the circuit of the rear braking gear depending on the rear axle load, changing of pressure in the braking system, effectiveness of interaction of the braking pads with the braking disks and drums.

The simulation model allows to estimate not only dynamics of the automobile at braking but dynamics of each wheel as well, which is represented in Figure 4 – changing of the wheels rotational speed.

![Figure 4. Changes of the wheels rotational speed](image.png)

Speed of the wheels differs because of the road surface unevenness. Changing of the wheels rotational speed from the average value is realized by means of supplementing of a random variable from the fixed range.

5. Conclusion
The simulation model of the braking system has been built up. The model allows to observe dynamics of mechanical and hydraulic elements of the system being developed, as well as of the existing ones by their operational characteristics, to optimize parameters of the braking system elements as well as the algorithm of its control system operation depending on the task set. Thus, the synthesized simulation model ensures saving time and material expenditures on the braking system development due to conducting simulation experiments.

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