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Research of the vacuum brake booster working process

The creation of a laboratory installation was carried out with an aim to ensure the study of the working processes and characteristics of vacuum boosters as a part of hydraulic brake drives for vehicles with a gross weight of up to 3.5 tons for civilian usage, and armored vehicles with a gross weight of up to 8.5 tons designated for service and combat missions. Theoretical researches in this direction have been previously carried out by a number of scientists of the Department of "Automobiles" named after prof. Gredeskul A.B. in Kharkiv National Automobile and Road University, the results of which have been highlighted in a number of scientific papers. Comparison of the results of theoretical studies with the experimental ones, received on the laboratory setup and suggested in this paper, according to the experimental method described in the article, using the created electronic signal processing complex and sensor unit, made it possible to establish a discrepancy between theoretical and experimental studies within 6%. This complex for experimental research was created for the first time, thus allowing to obtain the results that confirm the theoretical studies of the vacuum boosters of the brake drive of cars, as well as revealed a number of dependencies between the weight and overall parameters of the under research unit, along with the number of functional relationships between the structural components of the vacuum boosters, which enables to significantly optimize its design.

Keywords: vehicles, active safety, brake system, vacuum brake booster, static and dynamic characteristics, experimental research, technique, equipment.

Introduction

An analysis of the state of traffic safety in the world in general [1] and in Ukraine in particular [2] indicates the need for an urgent solution to the problems of accidents. A significant number of road traffic accidents occur due to insufficient active safety of vehicles, which is significantly determined by the efficiency of the vehicle braking system [3–5].

The vacuum brake booster is the most common service device for the brake systems of cars and light-duty vehicles [6, 7], the operation of which is provided both in the sectors of the national economy and in the automotive equipment of the National Guard of Ukraine. The efficiency and quality of its work largely determine the ergonomic conditions and the effectiveness of the brake control [8, 9] and, ultimately, the active safety of the car [6, 10]. Recently, the vacuum booster is increasingly not only a device for reducing the force on the brake pedal, but also an automatic device that corrects the actions of the driver (anti-lock braking system (ABS) and a motion stabilization system (ESP) [11], an emergency braking system Brake Assist (BAS) [12], etc.), which simplifies driving (preventive safety systems [13], energy recovery systems in hybrid and electric vehicles [14, 15], etc.). Therefore, improving the working process of the vacuum brake booster is the most important task to improve the active safety of the car.

The relevance of the topic lies in the fact that in order to reduce the accident rate of vehicles in the process of braking, it is necessary to implement a number of measures in the field of research support to improve brake drives [16–18]. One of these areas is the development of methods for the development of efficient vacuum brake boosters, which are produced in Ukraine. Currently, this is hampered by insufficient knowledge about their operational processes, as well as the lack of scientifically based generalized criteria for evaluating effectiveness [19–23].

Research objectives:

– study of working processes in a two-chamber vacuum amplifier;
– determination of static and dynamic characteristics of a two-chamber vacuum amplifier;
– comparison of theoretical and experimental results.

To achieve the goals set, the following tasks were solved:
– development of experimental research methodology;
– creation of an experimental facility;
– development and preparation of a measuring and recording complex based on a modern element base;
– implementation of a complex of experimental studies provided for by the program;
– processing the results of experiments and performing their analysis.

Object of the research — the working process of the vacuum brake booster.

The subject of the research is the increase in the efficiency of vacuum boosters of the brake drive.

Research methods. Methods of generation, selection and analysis of information were used to determine the state of the problem and to set the research objectives. In experimental studies of the working processes of vacuum boosters of the brake drive, the method of full-scale experiment was used.

The scientific novelty of the results obtained is that: for the first time, a structural analysis was carried out and the relationships between the elements of a vacuum amplifier were determined, which made it possible, using the proposed criteria, to determine its rational structure; regularities of interaction of structural elements and their influence on the working process, as well as the efficiency of vacuum boosters of the brake drive have been clarified.

A number of scientists of the Department of “Automobiles” named after A.I. d.t.s., prof. Gredeskula A.B., at Kharkiv National Automobile and Road University, have made a range of researches which are reflected in a number of scientific papers [8, 24–28]. Comparison of the results of theoretical studies obtained in these works with the experimental ones obtained on the laboratory setup suggested in this work, according to the experimental method described in the article, using the created electronic signal processing complex and a sensor unit, made it possible to establish a discrepancy between theoretical and experimental research within 6 %. To study the working process of the vacuum brake booster, a special installation was developed and created. The installation contains a system for supplying energy to a vacuum amplifier (vacuum) and an input signal formation mechanism (compressed air), an amplifier load and a measuring complex.

The energy supply system allows you to create, control and maintain the required level of vacuum in the vacuum cavities of the amplifier. The input signal generation mechanism provides the necessary level and nature of the force change on the amplifier pusher. This mechanism is a pneumatic chamber with an adjustable throttle at the inlet. To study the static characteristics, the pneumatic chamber is replaced by a lead screw. The main brake cylinder connected to the brake mechanisms is used as a booster load.

Improving the design, as well as the working processes of the units and apparatus of the hydraulic brake drive of a car, is based on the results of theoretical and experimental studies. The reliability of theoretical provisions fully depends on the level of experimental research. Theoretical studies carried out by the authors in [8, 24–28] required experimental confirmation, as a result of which it became necessary to create a special installation for studying the working process of a vacuum brake booster.

The developed mathematical model is based on the results of analysis and synthesis of the constituent elements of the Vacuum brake booster, using a gas dynamic model. Features of the working process are considered taking into account the gas-dynamic model shown in Figure 1. In accordance with the scheme of Figure 1. Vacuum brake booster has a body divided by a partition into two chambers. The chambers are divided by pistons into cavities 4, 5, 8 and 9. The cavities 9 and 5 are permanently connected to a vacuum source.

The connection of cavities 4 and 8 depends on the mode of operation. The air resistance between the cavities depends on the cross section of the throttles $Д_a$, $Д_b$ and $Д_к$.

The mathematical model of the dynamic state of the pusher has the form

$$F_T + F_{KH} - M_T \cdot \ddot{X}_T - k_T \cdot (\dot{X}_T - \dot{X}_1) - F_A - F_B - F_{TP} - F_H = 0. \quad (1)$$

During the movement of the pusher, the force from the FKH valve remains unchanged. The friction force of the pusher relative to the piston is non-linear

$$F_{TP1} = \begin{cases} F_{TP1} \cdot sign(\dot{X}_T - \dot{X}_1) \; if \; \dot{X}_T \neq \dot{X}_1, \\ F_{TP1} = 0 \; if \; \dot{X}_T = \dot{X}_1. \end{cases} \quad (2)$$

The relative displacement of the pusher and piston leads to the actuation of the switchgear and the mass flow of air into the atmospheric cavities has dependence

$$G_a = f_a \cdot p_a \cdot V_{кр} \cdot \varphi(\sigma). \quad (3)$$

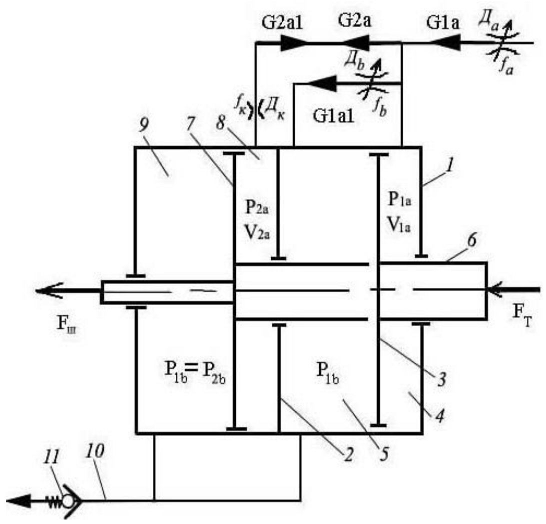


Figure 1. Scheme of the gas-dynamic model of a two-chamber Vacuum brake booster

The expenditure function $\varphi(\sigma)$ is taken in the following form

$$\varphi(\sigma) = \sqrt{\frac{1-\sigma_a^2}{2\cdot k\cdot(\xi_a - \ln\sigma_a)}}\ , \tag{4}$$

and the resistance coefficient of the atmospheric valve

$$\xi_a = 0{,}55 + 4\cdot\left(\frac{b_T}{d_a} - 0{,}1\right) + 0{,}176\cdot\left(\frac{d_a}{h_{кл}}\right)^2 . \tag{5}$$

The following assumptions are made in the model: rarefaction in vacuum cavities is constant, and the temperature regime is also unchanged.

A change in pressure in atmospheric cavities leads to the formation of additional forces on the booster pistons. Since the pistons in the investigated Vacuum brake booster do not have a rigid connection, when developing the model, it became necessary to confirm the hypothesis about the movement of the pistons without separation from each other during the working process.

To theoretically confirm this hypothesis, the equations of the dynamic state of the piston of the first chamber

$$M_1\cdot\ddot{X}_1 + f_1\cdot\dot{X}_1 + R = S_1\cdot\Delta P + f_{T1}\cdot\left(\dot{X}_T - \dot{X}_1\right) + R_1 + S_У\cdot\left(P_0 - P_{b1}\right), \tag{6}$$

replaced by an equation for the reaction of the dynamic component of the force of the second piston. The condition for the absence of contact break is the value for the reaction between the pistons R>0. This condition is met by the following relations:

$$S_1\cdot\left(P_{1a} - P_{1b}\right) + f_{T1}\cdot\left(\dot{X}_T - \dot{X}_1\right) + F_{ПР} - \left(S_У - S_Ш\right)\cdot\left(P_0 - P_b\right) + S_У\cdot\left(P_0 - P_{1b}\right) - f_1\cdot\dot{X}_1 - M_1\cdot\ddot{X}_1 \le 0\,, \tag{7}$$

$$\ddot{X}_1 \le \frac{S_1\cdot\left(p_{1a} - p_{1b}\right) + f_{T1}\cdot\left(\dot{X}_T - \dot{X}_1\right) + F_{пр} - \left(S_y - S_ш\right)\cdot\left(p_0 - p_b\right) + S_y\left(p_0 - p_{1b}\right) - f_1\cdot\dot{X}_1}{M_1}\,. \tag{8}$$

The results of the calculation of expressions (6), (7), (8) using the Simulink application of the MATLAB environment [29] in the form of a graphical dependence of the reaction between the pistons during braking are shown in Figure 2.

The above dependence theoretically confirms the hypothesis of the movement of pistons without separation from each other in a two-chamber vacuum booster.

Given the confirmation received, the mathematical model of the two-chamber Vacuum brake booster is simplified. The model, which takes into account the masses of individual pistons, has been converted to a single-mass model.

The force on the pistons is formed due to the pressure difference. The value of pressure in atmospheric cavities varies depending on the mass flow of air, as well as changes in the volume of cavities in accordance with the equations:

$$\frac{dP_{1a}}{dt} = \frac{G_{1a} - S_1 \cdot P_{1a} \cdot \dot{X}_1}{V_{1a} + S_1 \cdot X_1} \cdot k, \tag{9}$$

$$\frac{dP_{2a}}{dt} = \frac{G_{2a} - S_2 \cdot P_{2a} \cdot \dot{X}_1}{V_{2a} + S_2 \cdot X_1} \cdot k. \tag{10}$$

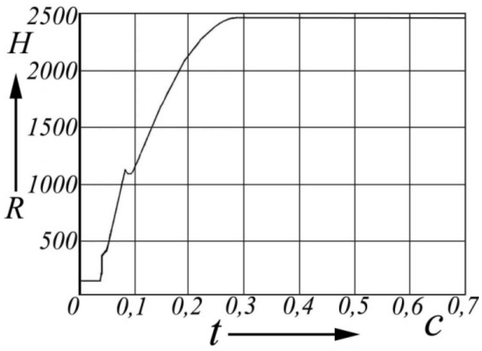


Figure 2. Dependence $R = f(t)$

The connection between the distribution and actuating devices is performed by the tracking device. The scheme of the most common tracking device is shown in Figure 3.

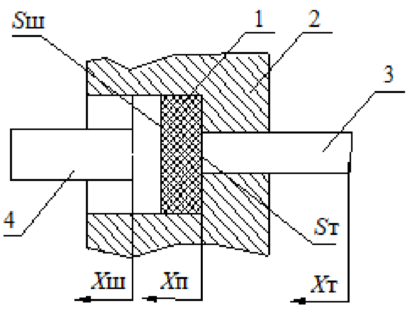


Figure 3. Scheme of the studied tracking device: *X*т, *X*п, *X*ш — displacement of the pusher, piston and rod, respectively; *S*т, *S*ш are the areas of reactive washer 1 interacting with the pusher and rod, respectively

During operation of the Vacuum brake booster, pressure builds up in reaction disc 1. The change in pressure depends on the relative position of the pusher 3, piston 2 and rod 4 and can be described by the following mathematical expression:

$$\frac{dP}{dt} = \frac{\left[\dot{X}_П \cdot \left(S_Ш - S_T\right) + \dot{X}_T \cdot S_T - \dot{X}_Ш \cdot S_Ш\right] \cdot E}{V_{РШ}}, \tag{11}$$

on the other side

$$\frac{dP}{dt} = \frac{\dot{F}_S}{S_Ш}, \tag{12}$$

where $\dot{F}_S$ — the rate of change of force on the rod according to the dependence $\dot{F}_S = f\left(X_Ш\right)$.

In this case, the speed of movement of the rod has the form

$$\dot{X}_Ш = \frac{\dot{X}_П \cdot \left(S_Ш - S_T\right) + \dot{X}_T \cdot S_T - \frac{dP}{dt} \cdot \frac{V_{РШ}}{E}}{S_Ш}. \tag{13}$$

The developed mathematical model is implemented in the Simulink application of the MATLAB environment. The mathematical model and the method of its implementation make it possible to expand the possibilities of choosing and optimizing the parameters of promising Vacuum brake boosters.

Special installation for studying the working process of the vacuum brake booster

This article suggests the development of a modern measuring and recording complex designed for experimental studies of an automobile hydraulic brake drive with a vacuum booster.

Equipment for research of working processes and characteristics of vacuum amplifiers.

To study the working processes and characteristics of vacuum amplifiers, a laboratory setup was developed, the block diagram of which is shown in Figure 4.

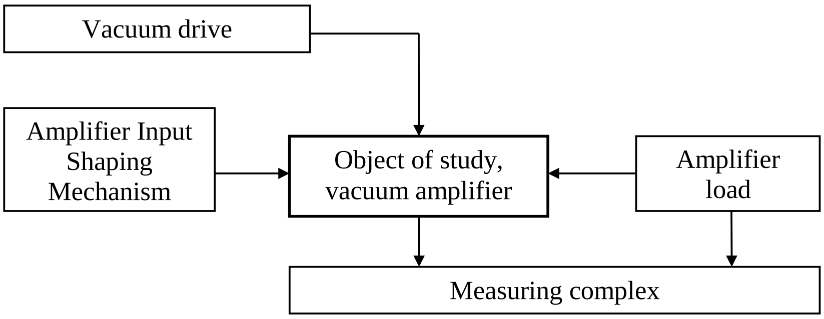
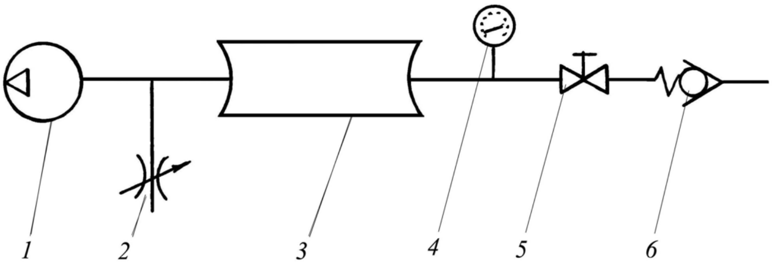


Figure 4. Structure of the laboratory setup

To provide vacuum, a vacuum drive was used, made according to the scheme shown in Figure 5.

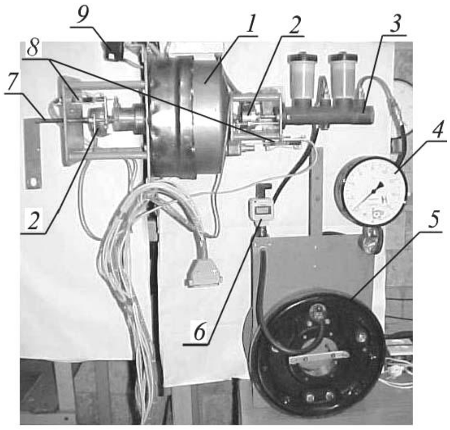


1 — vacuum pump; *2* — choke of variable cross section;
3 — vacuum receiver; *4* — vacuum gauge; *5* — uncoupling valve; *6* — check valve

Figure 5. Diagram of the vacuum drive

As a vacuum pump pos. 1 in Figure 5, a SO 7B reciprocating compressor unit with an air flow rate of at least 0.5 m3/min is used. To maintain the vacuum level, a variable cross-section throttle 2 was used in the line between pump 1 and vacuum receiver 3. Receiver 3, with a volume of 20 liters, is designed to smooth out the rarefaction pulsations and provide a vacuum reserve. To control the vacuum in the system, VP4-UU2 vacuum gauge is installed. Vacuum installation allows to obtain a stable level of vacuum up to 20 kPa absolute pressure.

The load of the investigated vacuum booster is a hydraulic drive, consisting of a main brake cylinder of the “Tandem” type with an inner diameter of 28 mm. Separate cavities of the master cylinder are connected by flexible hoses to the working cylinders of two drum brake mechanisms. The main brake cylinder and brake mechanisms are serial components of the brake system of a UAZ-3151 car in civilian design or KrAZ Cougar for the needs of the National Guard of Ukraine. Visual control of pressure in the hydraulic drive circuits is carried out by MP4-UU2 manometers with a pressure range of 0-16 MPa, a division value of 0.2 MPa and an accuracy class of 1.5. To register the pressure in the hydraulic drive, a KRT-7 sensor is installed. The location of the equipment on the experimental setup is shown in Figure 6.

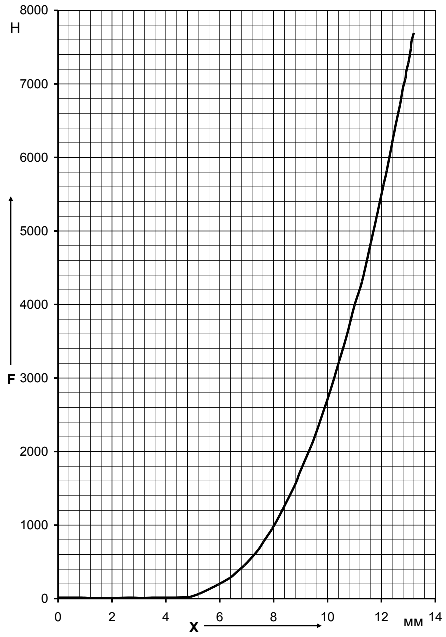


1 — vacuum brake booster under research; *2* — force sensors; *3* — the main brake cylinder; *4* — manometer; *5* — brake mechanisms with active and passive brake shoes (2 brake mechanisms); *6* — pressure sensor; *7* — screw device for forming the input signal; *8* — movement sensors; *9* — vacuum sensors

Figure 6. Location of equipment in the laboratory setup

On the input side of the vacuum booster, a bracket of increased rigidity is installed, made in the form of a straight parallelepiped. The amplifier under study is installed on one of the bases. On the opposite base, the installation of loading devices of the amplifier is provided. The bases are connected with pins. A force sensor is installed between the loading device and the pusher of the amplifier. A bracket for mounting displacement sensors is fixed on parallel studs. The bases of the pusher and piston displacement sensors are mounted on the bracket, and the movable sensor rods are connected to the booster pusher and piston. A smaller bracket, similar in design, is located between the vacuum booster outlet and the main brake cylinder of the load. There are also sensors for force and movement of the amplifier rod. To form the input signal of the amplifier under study, two variants of devices are provided. The first option is mechanical, screw (pos. 7, Fig. 6). It allows you to consistently set a stable rigid position of the booster pusher. The thread pitch of the screw pusher is 1 mm. The second variant of the device for forming the input signal of the amplifier is pneumatic.

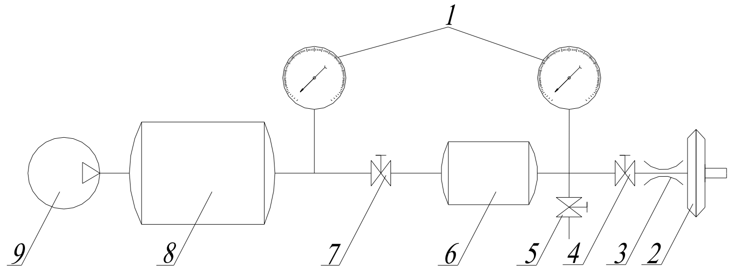
The characteristic of the load is the dependence of the force on the piston of the main brake cylinder on its movement. The load characteristic obtained on the experimental setup is shown in Figure 7.



F — force at the entrance of the main brake cylinder; X — movement of the piston of the main brake cylinder

Figure 7. Load characteristic of the vacuum booster

The general scheme of a pneumatic drive with an input signal conditioning device is shown in Figure 8.

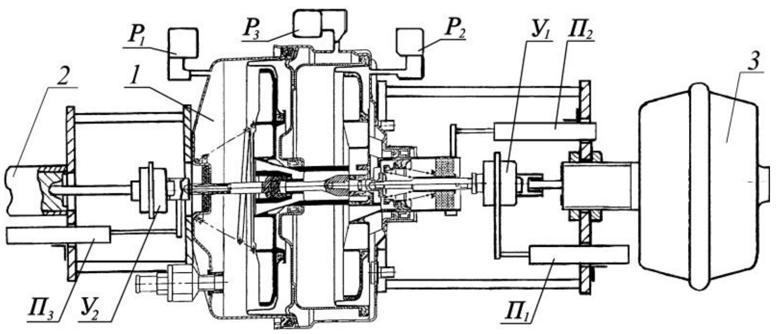


1 — pressure gauges; *2* — pneumatic chamber type 9; *3* — throttle; *4* — valve for flowing the receiver into the pneumatic chamber; *5* — valve for setting the pressure in the receiver; *6* — working receiver; *7* — valve for filling receiver 6; *8* — storage tank; *9* — stationary compressor

Figure 8. Scheme of the pneumatic drive of the experimental setup

The composition of the pneumatic actuator Figure 8 includes a stationary compressor *9* with a storage capacity of 200 l, a working receiver *6* of a laboratory unit with a capacity of 20 l, pressure gauges *1* for controlling the pressure in the pneumatic drive and the working receiver, as well as filling valves *7* and flow *4*, *5* of the working receiver *6*. Pneumatic chamber *2* is installed coaxial to the pusher of the studied amplifier. Air is supplied from the working receiver to the pneumatic chamber by a manual push-button valve *4*. The filling rate of the pneumatic chamber is provided by a constant-section throttle *3* installed at the inlet of the pneumatic chamber.

The placement of the elements of the investigated vacuum amplifier relative to the load and the device for forming the input signal is shown in Figure 9.



1 — vacuum booster under research; *2* — load; *3* — pneumatic chamber;
P_1, P_2, P_3 — displacement sensors; $П_1$, $П_2$, $П_3$ — vacuum sensors; $У_1$, $У_2$ — force sensors

Figure 9. Layout of the vacuum amplifier on the experimental setup

Technique of performing research on the experimental facility

When performing research on the experimental setup, the following parameters of the vacuum amplifier were measured and recorded:

– force on the pusher;
– force on the rod;
– pusher movement;
– piston movement;
– rod movement;
– pressure (vacuum) in the cavities of the amplifier.

The investigated physical processes require the use of high-precision and high-speed measuring instruments. Processing and analysis of the results is most expediently performed using modern digital computers (PC). Thus, the narrow specialization of the performed research led to the creation of a special measuring and recording complex.

Automated system for measuring and recording complex of working processes of vacuum brake boosters

Structural measuring and recording complex consist of three parts. The first part includes sensors for measuring the physical quantities of the studied parameters. The second part consists of pre-processing equipment, recording and issuing information about the parameters under study. The third part of the complex provides the necessary levels of power supply for sensors and equipment for processing and issuing information.

Taking into account the technical requirements for the implementation of the experiment and the results of the analysis of the products of the world's leading manufacturers of measuring equipment, the necessary measuring instruments were determined and purchased.

Strain gauges model LPX manufactured by Precision Transducers Ltd are used for force measurement. The experimental setup uses LPX sensors with force measurement ranges F = 0–2500 N and 0–10000 N.

With the help of this complex, you can solve the following tasks:

a) determination of the static characteristics of the dual-circuit master brake cylinder, single-chamber and double-chamber vacuum brake boosters;

b) determination of the dynamic characteristics of the hydraulic drive and the vacuum brake booster;

c) determination of the static and dynamic parameters of the working process of the vacuum brake booster.

To solve these problems in the process of research, it is necessary to obtain information on measuring the forces and displacements of the pusher, the booster rod, the degree of valve opening, the level of rarefaction in the working cavities of the booster, and the fluid pressure in the hydraulic brake drive circuits [8, 24, 27]. Based on the analysis of the designs of hydraulic brake drives of cars [6], the ranges of measured values were determined:

– force on the pedals: 0...500 N;
– force on the pusher: 0...2500N;
– force on the rod: 0...10000 N;
– movement of the rod and pusher: 0...50 mm;
– rarefaction in the working cavities of the amplifier: 0...0.09 MPa;
– pressure in the hydraulic drive of the brakes: 0...15 MPa.

Analysis of the products of the world's leading manufacturers of measuring equipment [9, 20, 22, 23, 30–32] was carried out taking into account the ratio of functional properties — price. As a result of this analysis, the following measuring devices were identified:

– for force measurement, LPX model sensors manufactured by Precision Transducers Ltd (New Zealand) with force measurement ratings up to 500 N, 2500 N and 10000 N;
– for measuring displacements, precision potentiometric sensors model CLP–13-50 manufactured by Megatron (Germany);
– for measuring pressure in the cavities of the vacuum booster BOSCH sensors series 0261230004 (Germany);
– to measure pressure in the hydraulic drive, the following sensors: strain gauges of the D, MD and KRT-7 series and the DM 5001, DM 5007 series.

During the development of the measuring and recording complex, the problem of providing various levels of power supply to sensors and stabilization, different in type (current and voltage) and the level of output signals, was solved. In addition, the peculiarity of the studied work processes was taken into account — the measurement and registration of fast and slow processes [33, 34]. For the rational use of the amount of memory, automatic measurement of the data recording interval was applied depending on the speed of the process. As a result, a circuit of a special electronic signal processing unit (SPU) was developed. Designed by SPU, designed for simultaneous use of 12 channels and has the following functionalities:

– ensuring stable power supply of channels;
– noise filtering and signal stabilization;
– calibration of sensors;
– determination and setting of the initial value of the measured parameter;
– testing and control of serviceability of channels;
– automatic mode of measurement and registration of parameters;
– accumulation, reading of parameters and cleaning of the system.

The structure of one SPU channel and the algorithm of operation of the electronic unit are presented respectively in Figure 10 and Figure 11.

According to the SPU channel structure shown in Figure 10, first, the sensor signal is amplified, stabilized, and digitized. Digital signals are fixed and accumulated. Each channel has the ability to calibrate the signal using an external keyboard and display the accumulated information.

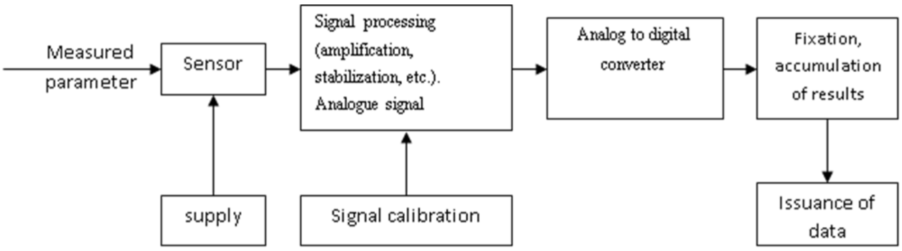


Figure 10. SPU channel structure

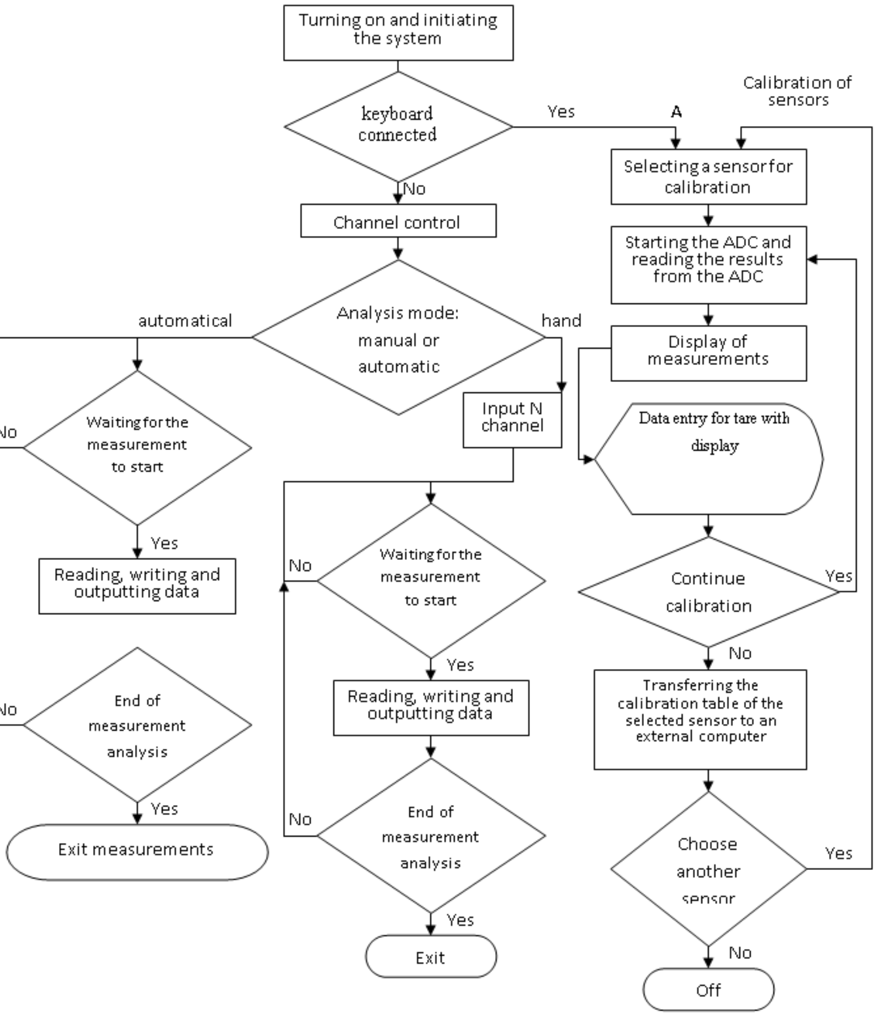


Figure 11. Algorithm of operation of the electronic unit SPU

According to the algorithm (Fig. 11), the SPU works as follows. When the measuring complex is turned on, the entire SPU periphery is initiated.

After initiation, the sign of connecting an external keyboard is checked. Based on the connection, the mode of further operation is selected:

– with the connected keyboard the tare mode;

– without keyboard connection – measurement mode.

In the calibration mode, the system displays information about the calibration with the number of the sensor and the corresponding channel of the analog-to-digital converter (ADC) on the graphic display.

After starting ADC, the measured value is displayed on the display. The equivalent calibrated value of the parameter and the command to fix this value by the system are set from the keyboard. Then, the following values are fixed similarly until the sign of the end of the calibration process is entered.

After calibration is completed, the measurement mode is set: manual or automatic, and the system proceeds to control the ADC channels. Then the connection and serviceability of sensors is checked with visual control of information on the display. After testing the sensors, the system analyses the operating mode: manual or automatic. Manual mode provides for viewing the measurement result on the display. ADC channels are triggered by a process start signal. Information is read from them and written to the random access memory (RAM) of the controller. The measurement results are displayed if necessary.

Measurements in automatic mode are performed similarly to manual ones, but the results are accumulated in blocks in the form of numerical arrays in RAM for further use for processing on an external PC. The SPU electronic element base is combined on three boards, as shown in the block diagram of Figure 12.

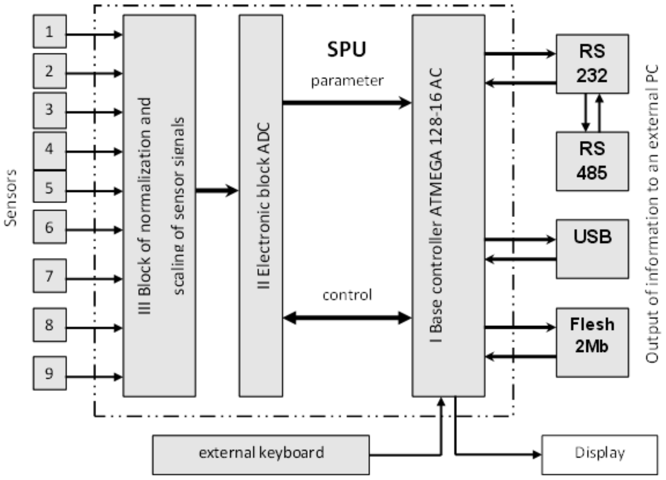


Figure 12. Block diagram of the measuring complex

The measuring complex, the block diagram of which is shown in Figure 3 has nine channels with sensors, signal processing unit (SPU) with keyboard, display via PC interface. To study the working process of a vacuum amplifier, it is necessary to know the change in the level of rarefaction in the cavities, the change in the forces on the pusher and rod, the coordinates of the movement of the pusher, piston, rod.

The board I of the controller is designed to control the entire measuring complex and has an interface connection with a PC. The controller is based on the ATMEGA 128-16 AC microprocessor.

For communication with external devices, I/O and storage of temporary data, a rewritable Flash program memory module is used.

The measuring system for communication with PC has three interfaces RS-232, RS-485 and USB. The RS-232 interface scheme is based on the ADM 202 EAN chip. The RS-485 interface is based on the MAX 487E CPA chip. For USB communication, the FT 245 BM-FTDI chip is used.

The measurement results are displayed on the BG12864A GPLW graphic display.

Board II ADC contains 12 independent analog-to-digital channels. Each channel is based on AD 7492 AR-5 chips.

The signals from the sensors are pre-processed on the electronic unit III. The sensor signal normalization and scaling unit contains LM 358 operational amplifiers. The pre-processed signals from the sensors enter the switch, are processed at the voltage limiter, and then go directly to the ADC. All ADC channels are launched simultaneously, then each of them is selected using decoders and read into the controller's RAM.

The complex is powered by DC voltage 12V. Power supply of the sensors is from the signal processing unit with a voltage of 5V.

The non-linearity of the output signals of pressure, vacuum and force ±0.2 %. Non-linearity of motion signals ±0.3 % and resolution <0.01 mm.

The overall dimensions of the signal processing unit are 140×120×60 mm. Weight is 0.38 kg.

To measure the force, LPX Precision Transducers with measurement limits of 2500 N and 10000 N are used. The combined error of the sensors is 0.1% and the allowable overload is 150 %.

The movement of the pusher, piston and booster rod is measured by CLP-13-50 sensors. These sensors have a resolution of less than 0.01 mm with a linearity tolerance of up to 0.7–1.3 % at a travel speed not exceeding 5 m/s. Such accuracy is sufficient to estimate the relative movement of the pusher and piston, rod and piston.

The installation of force and displacement sensors does not require changes in the design of the vacuum booster.

The research facility is equipped with three vacuum sensors BOSCH series 0261230004 with absolute pressure measurement limits from 20 to 100 kPa. When studying the working process of two-chamber vacuum amplifiers, rarefaction sensors are connected to both atmospheric cavities and the vacuum cavity. In the case of a single-chamber amplifier study, only two vacuum sensors are used. Connecting the measuring cavities of the vacuum sensors to the corresponding cavities requires a change in the design of the amplifier housing. It is quite simple to do this by making axial holes in the corresponding bolts for fastening the amplifier and the main brake cylinder.

The layout of the sensors on the installation is shown in Figure 9, and a general view of the setup and sensors is shown in Figure 13.

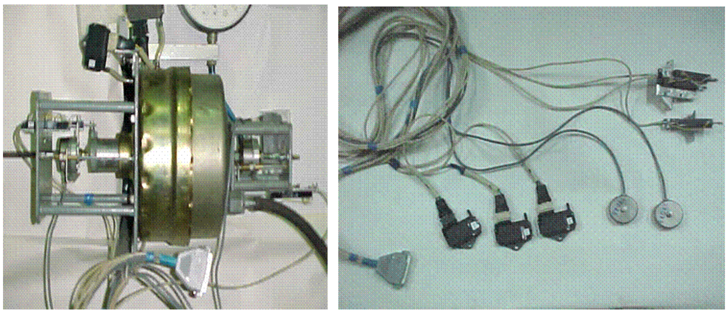
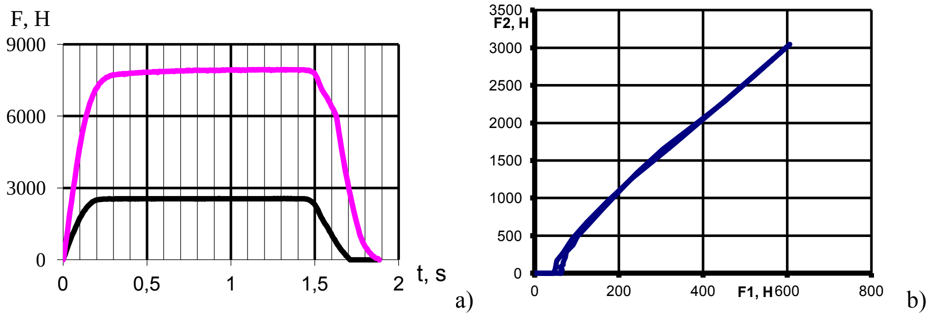


Figure 13. Automated system for measuring and complex recording of working processes of vacuum brake boosters

Results of experimental researches

Before the experiment, the sensors are calibrated, the elements and parameters are set, which determine the initial conditions and characteristics of the input action in accordance with the research program. After starting the control program on the PC, the input signal conditioning device is activated. Registration of changes in effort, rarefaction, and displacements is automatically recorded in the memory of a personal computer in the form of a matrix with a quantization of 0.1–100 mls. The quantization level is set before the experiment, depending on the speed of the process.

After the experiment, the result is presented on the computer monitor as a graph $Fi = f(t)$, which can be used to evaluate its quality. An example of an "electronic oscillogram" is shown in Figure 14 *a*. Processing of the matrix of experimental data is carried out in the EXCEL software. In this case, it is possible to construct graphical dependences of the function under study on time or any other process parameter (Figure 14 *b*).



a) "electronic oscillogram"; *b*) dependence of the force at the output of the amplifier on the input force

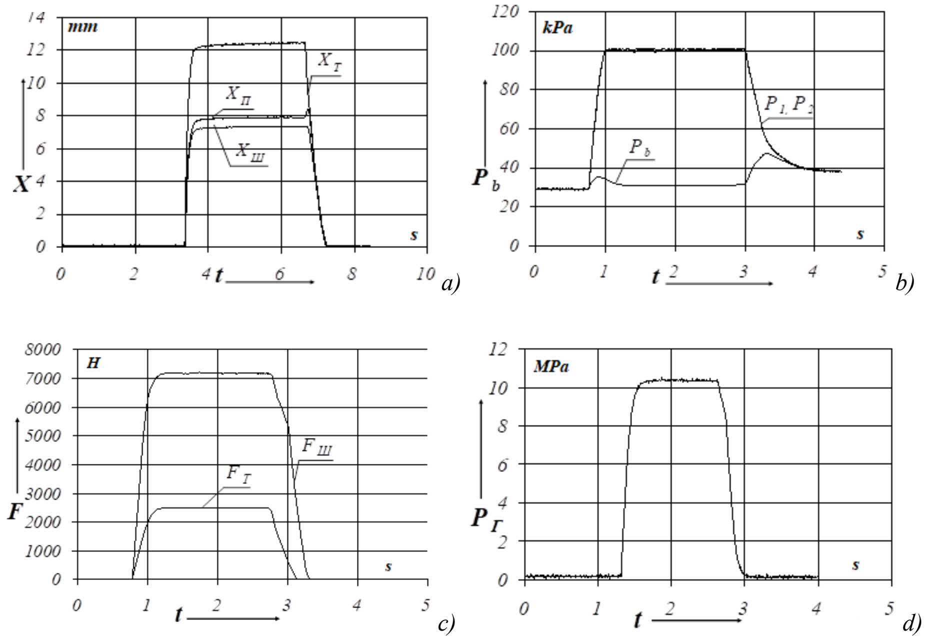
Figure 14. The results of processing the results of the study

The name of the data matrix file is assigned automatically and represents the time of the experiment.

To obtain information about the operation of the vacuum amplifier, a dosed force was applied to its input (pusher). The dosing of the force in terms of magnitude and speed was provided by changing the pressure in the pneumatic chamber *3* (Fig. 9). In the processes of imitation of braking and releasing, the following were measured: the movement of the pusher, piston and rod; force on the pusher and rod; pressure in vacuum and atmospheric cavities. As a result of the created processing technique, absolute and relative data on the parameters of the workflow were obtained.

The study of the dynamics of the working process was carried out with a consistent study of the influence: liquefaction in a vacuum cavity; force on the pusher; the rate of force application to the pusher.

The general view of the experimental dynamic characteristics is shown in Figure 15.



a) displacement *X* = *f* (*t*); *b*) rarefaction *Pb* = *f* (*t*); c) efforts *F* = *f* (*t*); d) pressure in the load drive *RG* = *f* (*t*);
Xт, Xп, Xш — displacement of the pusher, piston and rod, respectively; Pb, P1, P2 — change in pressure in the vacuum cavity and atmospheric cavities; Fт, Fш — force on the pusher and rod, respectively

Figure 15. General view of the obtained experimental dynamic characteristics

As a result of the experiments performed, it turned out that:

– the vacuum level practically does not affect the time of the braking process;

– the pressure equalization time in the vacuum and atmospheric cavities increases with an increase in the initial rarefaction;

– the braking process reduces the rarefaction in the vacuum cavity by an average of 6 kPa;

– with a decrease in the rate of effort on the pusher from 0.04 s to 0.3 s, the time for changing pressure in atmospheric cavities decreases by 0.2–0.24 s.

The theoretical position on the joint movement of the pistons without separation from each other is confirmed by the ratios of the movement of the pusher and the rod Xт>Xш. The influence of the rate of braking on the parameters of the working process Vacuum brake booster is shown in Table.

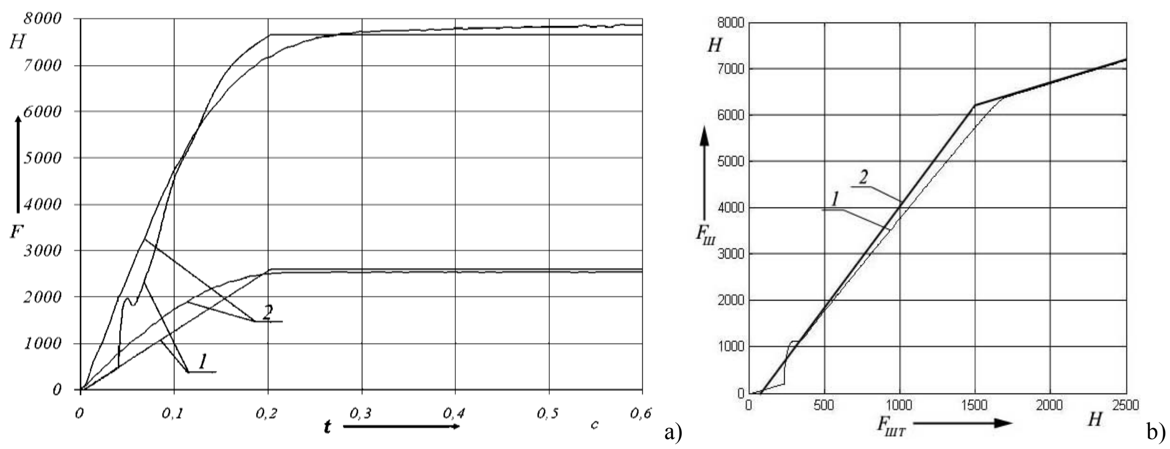
Also previously unknown data on the relative motion of the pusher, piston and rod, depending on the deformation of the follower element was obtained.

Subsequent experimental studies were carried out with the location of the brake system in full on the stand with the inclusion of the Vacuum brake booster created by it. The developed measuring and recording complex were used at the stand. The following parameters were measured: the force on the brake pedal and its movement; pressure in the hydraulic brake drive and pressure in the vacuum and atmospheric cavities Vacuum brake booster. The results obtained indicate minor deviations in performance due to the influence of the braking system. The errors of the static characteristics do not go beyond the recommended limits, and the dynamic characteristics confirm the high level of tracking action. The difference between the experimental and theoretical results when compared does not go beyond 6%. Comparison of the experimental dynamic and static characteristics of the Vacuum brake booster with the theoretical ones is shown in Figure 16.

T a b l e

The results of the study of the influence of the rate of input action on the working process of the vacuum amplifier

Process parameters	Parameter value									
t_{T3} – time of change of force on the pusher from “0” to F_{Tmax}, s	0.04	0.08	0.09	0.09	0.10	0.26	0.28	0.29	0.30	0.32
t_{31} – time of pressure change in atmospheric cavities during braking, s	0.75	0.64	0.75	0.76	0.68	0.35	0.20	0.48	0.30	0.46
$t_{Ш3}$ – time of change of force on the rod from “0” to $F_{Шmax}$, s	0.82	0.72	0.80	1.00	0.80	0.48	0.40	0.52	0.50	0.46
Δt – release delay, s	0.18	0.12	0.20	0.17	0.15	0.16	0.15	0.12	0.18	0.09
$t_{Ш3} - t_{31}$, s	0.07	0.08	0.05	0.24	0.12	0.13	0.20	0.04	0.20	0
P_{BH} – initial vacuum level, kPa	28	54	22	32	36	24	32	56	44	67
F_{Tmax} – maximum force on the pusher, kN	2.4	2.5	2.4	2.5	2.4	2.4	2.5	2.5	2.4	2.5
$F_{Шmax}$ – maximum, force on the rod, kN	7.2	5.4	7.6	6.9	6.4	7.5	6.8	5.2	6.0	4.4



a) dynamic response; *b*) static characteristic;
1 — results of mathematical modeling; *2* — results of the experimental study

Figure 16. Comparison of experimental and theoretical characteristics

The developed setup can be used not only to study the characteristics of the working process of vacuum amplifiers, but also to certify each manufactured amplifier. At the same time, each manufactured unit will have a serial number, a real characteristic, a release date, etc., which will make it easy to identify the product and detect fakes.

Conclusions

1. The existing assessment of the efficiency of amplifiers is carried out according to one parameter — the gain, which is understood as the ratio of the output force to the input force. This approach is logical, mainly when there is no energy supply from an additional source, that is, the amplifier is considered as an energy converter. This approach does not allow us to evaluate the efficiency of amplifiers on vehicles with different masses. The developed set of criteria for evaluating the efficiency of vacuum boosters of the brake drive made it possible to comprehensively evaluate the effectiveness of vacuum boosters.

2. As criteria for evaluating the effectiveness, it is proposed to use:

– criteria for evaluating the work of a unit of mass and unit of volume, which is the ratio of the work at the output of the amplifier, respectively, to its mass and building volume;

– criteria for evaluating the power of a unit of volume and unit of mass, which allow us to evaluate not only the compactness of the amplifier, but also its speed;

– coefficient of compliance and specific idling of the booster pusher, characterizing the layout volume of the pedal drive.

3. The use of the proposed set of criteria made it possible to find ways to reduce the volume and mass in the amplifier design by 30–40% compared to analogues.

4. The created measuring and recording complex is used for bench studies of the characteristics of vacuum amplifiers.

5. Work continues to improve it, aimed at using it to obtain output passport data in the production of brake system units, in particular, vacuum boosters.

6. In the future, with appropriate modifications, the created complex is supposed to be included in the automation system for managing the work processes of vehicle units.

7. The practical use of the results obtained is aimed at achieving a social effect on improving the working conditions of drivers and increasing the active safety of cars.

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Вакуумдық тежегіш күшейткіштің жұмыс процесін зерттеу

Зертханалық қондырғыны жасау толық массасы 3,5 тоннаға дейінгі азаматтық мақсаттағы автомобильдердің гидравликалық тежегіш жетектерінің және қызметтік-жауынгерлік міндеттерді орындауға арналған толық массасы 8,5 тоннаға дейінгі автобронетанк техникасының құрамындағы вакуумдық күшейткіштердің жұмыс процестері мен сипаттамаларын зерттеуді қамтамасыз ету мақсатында жүргізілді. Бұған дейін Харьков ұлттық автомобиль-жолдары университетінің т.ғ.д., проф. А.Б. Гредескул атындағы Автомобиль кафедрасының бірқатар ғалымдары осы бағытта теориялық зерттеулер жүргізумен айналысқан, олардың біразы ғылыми жұмыстарда көрініс тапқан. Теориялық зерттеулердің нәтижелерін осы жұмыста ұсынылған зертханалық қондырғыда орнатылған эксперименттік қондырғылармен, мақалада сипатталған эксперименттік әдістеме бойынша, сигналдарды өңдеудің электронды кешені мен датчиктер блогының көмегімен салыстыру теориялық және эксперименттік зерттеулердің сәйкессіздігін 6% шегінде анықтауға мүмкіндік берді. Эксперименттік зерттеулерді жүргізуге арналған бұл кешен алғаш рет жасалды және автомобильдердің тежегіш жетегінің вакуумдық күшейткіштерінің теориялық зерттеулерін растап қана қоймай, сонымен қатар зерттелетін тораптың салмақ пен габариттік параметрлері арасындағы бірқатар тәуелділіктерді, сондай-ақ вакуумдық күшейткіштердің құрылымдық компоненттері арасындағы бірқатар функционалдық қатынастарды анықтады, бұл оның дизайнын айтарлықтай оңтайландыруға мүмкіндік береді.

Кілт сөздер: көлік құралдары, белсенді қауіпсіздік, тежеу жүйесі, вакуумдық тежегіш күшейткіш, статикалық және динамикалық сипаттамалар, тәжірибелік зерттеулер, технология, жабдық.

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Исследование рабочего процесса вакуумного усилителя тормозов

Создание лабораторной установки проводилось с целью обеспечения исследования рабочих процессов и характеристик вакуумных усилителей в составе гидравлических тормозных приводов автомобилей с полной массой до 3,5 т гражданского назначения и автобронетанковой техники с полной массой до 8,5 т, предназначенной для выполнения служебно-боевых задач. Проведением теоретических исследований в этом направлении ранее занимался ряд учёных кафедры автомобилей им. д-ра техн. наук, проф. А.Б. Гредескула Харьковского национального автомобильно-дорожного университета, которые отражены в их научных работах. Сравнение результатов теоретических исследований с экспериментальными, полученными на предлагаемой в настоящей работе лабораторной установке по экспериментальной методике, описанной в статье, с помощью созданного электронного комплекса обработки сигналов и блока датчиков, позволило установить расхождение теоретических и экспериментальных исследований в пределах 6 %. Данный комплекс для проведения экспериментальных исследований создан впервые и позволил получить результаты, которые не только подтвердили теоретические исследования вакуумных усилителей тормозного привода автомобилей, но и выявили ряд зависимостей между весовыми и габаритными параметрами исследуемого узла, а также функциональные взаимосвязи между структурными компонентами вакуумных усилителей, что позволяет значительно оптимизировать его конструкцию.

Ключевые слова: транспортные средства, активная безопасность, тормозная система, вакуумный усилитель тормозов, статические и динамические характеристики, экспериментальные исследования, техника, оборудование.

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