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Contents

METHOD OF EXPERIMENTAL RESEARCH OF STEERING CONTROL UNIT OF HYDROSTATIC STEERING CONTROL SYSTEMS AND STANDS FOR THEIR REALIZATION

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Abstract. The original method of experimental studies of separate steering control units for the systems of hydro-static steering control of special machines is developed. It is proposed to create a load for the steering control unit in the form of a pressure difference in its output channels without the use of load-bearing hydraulic cylinders. The electrohydraulic circuitry of the stand was developed for the implementation of the proposed methodology. This allows us to analyze the quality of the operation of the steering control unit in conditions that correspond to different modes of operation of the steering system, and to determine the appropriate characteristics of the steering control unit at the oncoming and associated load.
Keywords*:* *steering system, steering control unit, test bench, test procedure, system parameters, counter and associated load*

INTRODUCTION

For today, hydro-static steering control system are used on a variety of self-propelled special machines, due to a number of advantages of such systems. Many scientific schools work to improve existing or create new steering systems [1, 2]. Such works on modernization and research of steering control units of hydro-static steering systems are carried out at Vinnitsa National Agrarian University [3].

One of the important issues that arise when creating new samples of technical objects, and especially such science-intensive ones as steering control units, is to conduct experimental research of their prototype samples [4]. The experimental studies are aimed at determining the parameters included in the mathematical model of the steering system, and checking the adequacy of this model, as well as determining the reliability and convenience (organoleptic quality assessment) of the steering control unit. In addition, there is a problem of conducting comparative tests of steering control units of different manufacturers.

ANALYSIS OF LITERARY DATA AND PROBLEM STATEMENT

For today there are various stands for experimental researches of systems of hydro-static steering control in general. Scheme of the most universal stand of such appointment is given on (Fig. 1) [5]. The tested hydraulic steering control system 1 contains a steering control unit 2 and an executive hydraulic cylinder 3. The steering control unit is connected by hydro-lines 4 and 5 with a power supply 6, consisting of a pump 7 and a safety valve 8.

The rod 9 of the executive hydraulic cylinder 3 is connected to the unit 10 which creates a load on the steering system.

The load in the form of force is created by an additional hydraulic cylinder 11 whose working cavities are connected to the output channels of the electrohydraulic tracking distributor 12. The electrical system for forming the control signal by the distributor 12 comprises the following basic elements, such as the displacement sensor 27 of the stock of the executive hydraulic cylinder, the force sensor 42, and the block 22, which generates an electrical signal that sets the magnitude and law of the load change on the steering system. This allows you to create a counter load (the load force operates in the opposite direction of movement of the stock of the executive hydraulic cylinder) or the associated (load force operates in one direction with the displacement of the stock of the executive hydraulic cylinder). These efforts can be permanent, or change according to a certain law (harmonious, triangular, accidental or any other).

The input shaft 43 of the steering control unit 2 is connected to the control signal formation unit 44. The control signal in the form of a rotation of the input shaft of the pump-dosing unit is formed by the hydromotor 45. The cavities of the hydromotor are connected to the output channels of the electrohydraulic tracking distributor 46, which controls the speed of rotation of this hydromotor. The electrical control signal generating system of the distributor 46 comprises such basic elements as an angular velocity sensor 50 and a block 48 that generates an electrical signal that sets the value and law of the change of control signal to the steering system. This allows you to set the value and direction of the constant speed of rotation of the input shaft of the pump-feeder. Or set the speed of rotation, which varies according to a certain law (harmonic, triangular, random, or any other).

This stand allows you to explore any static and dynamic characteristics of the steering system or to investigate the endurance of this system. The disadvantage of such a booth is that when testing steering control units with different working volumes of the dosing unit, it is necessary to change the hydraulic cylinders 3 and 11. In addition, the limited piston movement of these hydraulic cylinders limits the time of playback on the stand of a particular operating mode of the steering control unit. And this time the smaller the larger the speed of rotation of the input shaft.

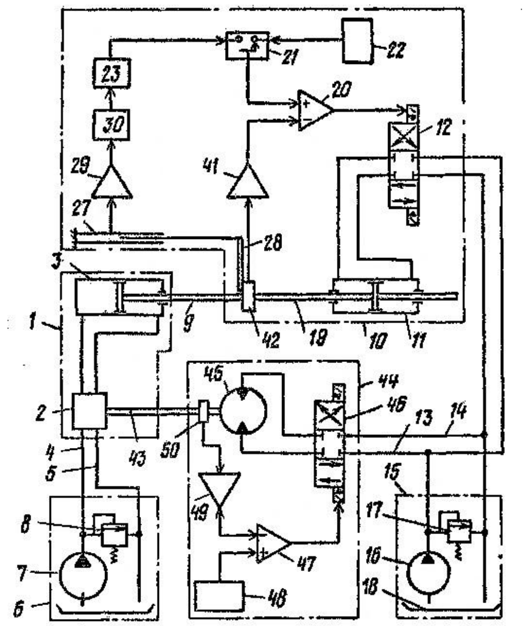


Fig. 1. Scheme of the bench for testing the steering system, in which follow-up electro-hydraulic distributors are used.

There is another test bench (Fig. 2) [6] in which the steering system, which contains the steering control unit 15 and the executive hydraulic cylinders 16, is tested. The control signal is set from the steering wheel, and the opposite cavities of the executive hydraulic cylinders are used to create the load. Counter loading is formed by antitussive, and by passing - by pressure in the direction of displacement given by the distributor 9 according to the direction of rotation of the steering wheel. Load size is given by chokes 5 and 6. This booth has a lower functionality than the previous one, but it is also intended to test the system of hydro-power steering in general. Therefore, it has the same disadvantages as the previous stand.

Well known stand for the testing of individual aggregates of static steering systems (Fig. 3) [7], including for the testing of dispensing pumps 14. However, in order to create a load, a hydraulic cylinder 24 is also used in it, which together with a lever 32 and a spring 33 allows forming both a counter, and an associated load. Although this hydraulic cylinder is not part of a static steering system, it limits the amount of fluid supplied from the steering control unit and the duration of the steering control unit operating time in a certain operating mode. Therefore, this stand also has drawbacks that are characteristic of the previous stands.

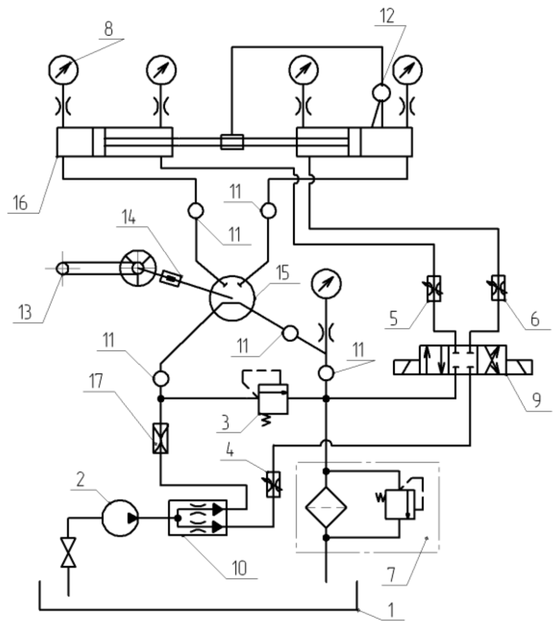


Fig. 2. Scheme of the test bench for the steering system, in which the load chokes were used:
1 – tank, 2 – pump, 3 - safety valve, 4, 5, 6 – throttle, 7 – filter, 8 – pressure gauge, 9 – spreader, 10 – flow divider, 11 - pressure sensors, 12 – displacement sensor, 13 – speed sensor, 14 – torque sensor, 15 – steering control unit, 16 – hydraulic cylinders, 17 – cost sensor.

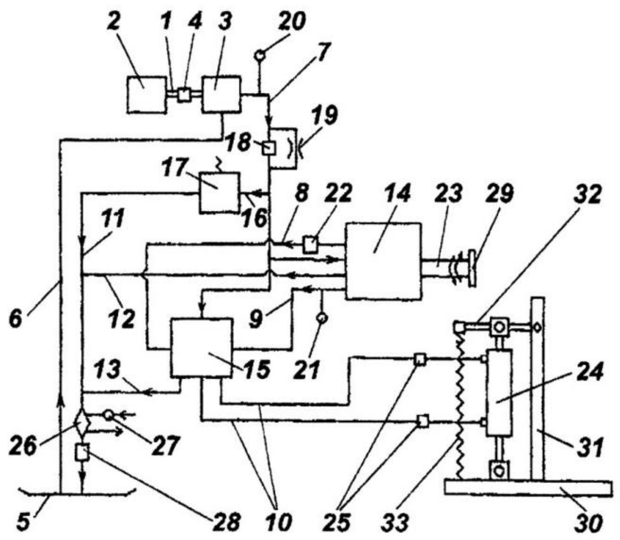


Fig. 3. Scheme of the stand for the testing of individual aggregates of hydro-power steering systems:
1 – drive shaft, 2 – electric motor, 3 – pump, 5 – tank, 7, 8, 9 – pressure lines, 10 – outgoing lines, 11, 12, 13 – drain lines, 14 – steering control unit, 15 – flux amplifier, 17 – safety valve, 18 – faucet, 19 – throttle, 20, 21 – pressure sensor, 22, 25 – cost sensors, 23 – drive shaft, 24 – hydraulic cylinder, 29 – torque sensor, 31 – stand, 32 – lever, 33 – spring.

PURPOSE AND OBJECTIVES OF THE RESEARCH

The purpose of this work is to develop a methodology for experimental studies of a steering control unit without the use of hydraulic cylinders to create a load. The next task of the work is to develop a booth scheme for the implementation of the proposed methodology of experimental research.

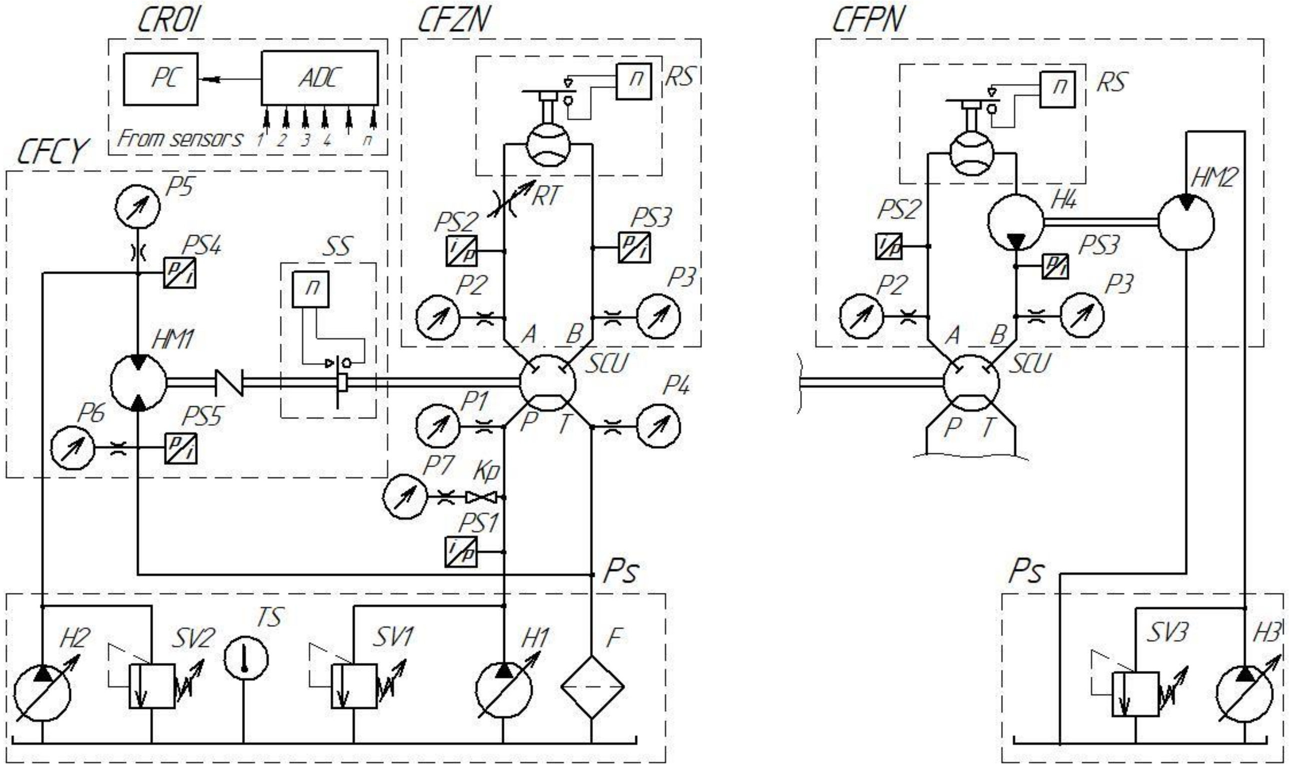
MATERIALS AND METHODS OF RESEARCH

The load on a hydro-static steering system is an effort on the executive hydraulic cylinder of this system, which is traditionally modeled during experimental tests. This effort is significantly different for steering systems of various technological machines - by mass, capacity, purpose, etc. Therefore, used hydraulic cylinders with different effective areas of the piston of the executive hydraulic cylinder, complete with which steering control units with different working volumes are used. But for loading pumps, there is a pressure drop in its output channels [9], which allows us to evaluate the performance of these products by modeling the pressure drop regardless of their working volume. Therefore, the differential pressure of Δp in its output channels is considered in the future as a universal load parameter of the steering control unit.

The nature of the load for the hydro-power steering system is related to the direction of the force on the executive hydraulic cylinder in accordance with the direction of rotation of the steering wheel. In accordance with this load, the steering system is divided into counter and associated. During the experimental research of the steering control units on the stand, it is necessary to form both types of load.

In the laboratory of the department "Machinery and equipment of agricultural production" of Vinnitsa National Agrarian University a special experimental booth was created for the study of pump-dosing devices of hydro-volume steering systems. It allows you to analyze in detail the operation of the dispensing pump at different operating modes of the system, providing control of the value and direction of the control signal and the load throughout the range of values that arise in practice.

The stand has a system for forming a control signal in the form of a rotation of the input shaft of the pump-dosing unit and a system for forming the load in the form of a pressure difference in its output channels. The electrohydraulic circuitry of the stand is shown on (Fig. 4). Since various methods of formation of counter and associated loads are used, a stand with a variable structure was implemented. In accordance with this, various schemes of the stand have been developed for the implementation of loads of different types. On (Fig. 4, a) is shown a complete scheme of the stand, in which the system of counter-load formation (SFZN) is implemented. On (Fig. 4, b) only the part of the booth circuit, in which the system of formation of the associated load (SFPN) is implemented, is shown. In this case, other systems of the stand are similar to those depicted on (Fig. 4, a).



a) b)

Fig. 4. Hydraulic diagram of the booth to determine the characteristics of the steering control unit; (a) - in the formation of counter-loads, (b) - in the formation of the associated load

The stand contains the steering control unit (SCU), the pumping station for the power supply of all stand systems, the system for forming the control signal (SPSS), the load formation system, as well as the system for registration and processing of information (SROI).

Steering control unit (SCU) (Fig. 4, a) by pressure channel P is connected to the pump H1 and the channel T - to the drainage channel of the pumping station. This reproduces the work of the steering control unit with the power system on the self-propelled machine. The pump H1 is made of regulated performance. This allows you to adjust the flow rate of this pump to a value that corresponds to the pump's power consumption for the steering system with the steering control unit of the test specimen size.

The system of forming a control signal sets the rotational motion of the input shaft of the pump-dosing unit, which simulates the rotation of the steering wheel on the self-propelled machine. For this purpose, a hydromotor *HM1* is used, the shaft of which is connected through a rigid coupling to the input shaft of the pump-dispenser. The working cavities of the *HM1* hydromotor are connected to the pumping station channels, which includes the output channel of the pump *H2* and the drain channel. The pump *H2* is made of regulated performance. This allows you to adjust the speed of rotation of the shaft of the hydraulic motor *HM1*, which sets the desired speed of rotation to the input shaft of the pump-dosing unit.

Output channels of the steering control unit *A* and *B* are connected to the load formation system. Formation of different types of load is realized by changing the structure of the stand. The system of formation of the counter (passive) load (Fig. 4, a) is implemented as a regulated throttle *RT*, which is connected to the output channels *A* and *B* of the dispensing pump. Adjusting the area of this throttle allows you to change the resistance of the flow of the working fluid through the outlets of the steering control unit. Due to this, at the output of the steering control unit, a load is formed in the form of a differential pressure Δp in its output channels, which reproduces overcoming a certain counter-load.

The system of formation of the associated (active) load (Fig. 4, b) is realized as a pump H4, the suction and output channels of which are connected to the output channels A and B of the dispensing pump. The pump shaft *H4* is driven by the *HM2* hydromotor, whose rotational speed is regulated by setting the flow rate of the pump *H3* of the pumping station. Adjusting the pump speed *H4* allows you to adjust a certain amount of negative pressure difference in the output channels of the dispensing pump, which reproduces a certain associated load.

This method of forming the counter and associated load for the steering control unit allows you to refuse the use of load hydraulic cylinders that interact with the executive hydraulic cylinders of the steering system [7, 8]. This significantly simplifies the construction of the stand and does not require the use of hydraulic cylinders for the implementation of both the system of hydro-turbine steering, and hydraulic cylinder load creation system.

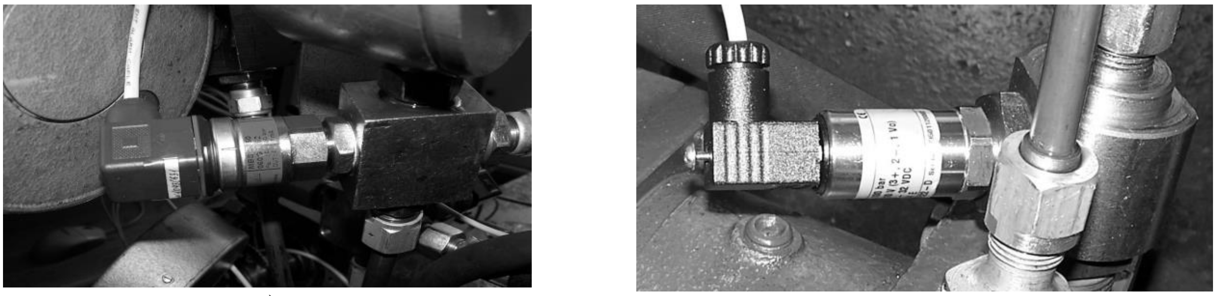
In addition, such a stand allows you to reproduce a certain mode of operation of the steering control unit for a long time, in contrast to the traditional stand, when this process lasts for several seconds at high speeds of rotation of the input shaft. This allows, at the stage of the experimental verification of the work of the prototype, to analyze the values of the parameters controlled on the stand, the quality of the work of the prototype and to assess the conformity of the state of the hydrosystem to the expected.

The bench is equipped with a control and measuring equipment, which allows to register the parameters of the system in a steady state and in dynamics. Parameters measured on the stand in a steady state are given in Table 1. For visual measurements of the pressure *P1 ... P7* in the steady state, bench pressure gauges type *DM*, accuracy class 0.6 are installed. Different sections of the hydro system used pressure gauges with different measuring ranges.

Two pressure gauges are installed in the pressure duct of the steering control unit - one P1 with a measurement range of up to 25 MPa, designed to control the pressure on the operating modes of the steering system, and another P7 that is connected through the faucet *Kp*, has a measurement range of up to 1,6 MPa and designed to control pressure in the absence of a control signal at the average position of the spool valve of the steering control unit.

For control of pressure during the analysis of dynamic processes on the stand, strain gauge pressure sensors with built-in amplifiers are installed, which allow to record changes in pressure over time in the corresponding sections of the hydrosystem. Pressure sensors PS1-PS5 on different sections of the hydraulic system are used with different nominal pressure. PS1, PS2 and PS3 sensors of the Danfoss (Denmark) MBS 3050 model (Fig. 5 a) have a nominal pressure of p_{nom} = 16 MPa, and pressure sensors PS4 and PS5 of the ADZ-NAGANO ADZ-SML-20 model (Germany, Japan) (Fig. 5, b) have a nominal pressure of p_{nom} = 10 MPa.

A photo of the stand for testing a steering control unit with a working volume of 160 cm^3/rotate during the counterload is shown on (Fig. 6).



a) b)

Fig. 5. Photos of pressure sensors: (a) the model MBS 3050 and (b) the model ADZ-SML-20

Table 1 - List of parameters that are measured on an experimental bench

Найменування Name	Unit of measurement	Value		Measurement error, %
		min	max	
Flush the input shaft of the steering control unit	*deg*	0	30	1,5
Rotation speed of the input shaft of the steering control unit	*rpm*	5	100	1
Torque transmitted to the input shaft of the steering control unit	*N·m*	0	120	4
Adjusting torque limitation on the input shaft of the steering control unit	*N·m*	5	120	4
Loading pressure difference in the output channels of the steering control unit	*MPa*	0	±25	1
Excess pressure applied to the outlet duct of the steering control unit	*MPa*	0	25	0,6
Pressure at the pressure line:	*MPa*			

pump H1		0	25	0,6
pump H2		0	12	
pump H3		0	25	
Consumption at the pressure line :	*l/min*			1,5
pump H1		8	126	
pump H2		5	31,8	
pump H3		6	63	
Working temperature	^{o}C	10	100	2

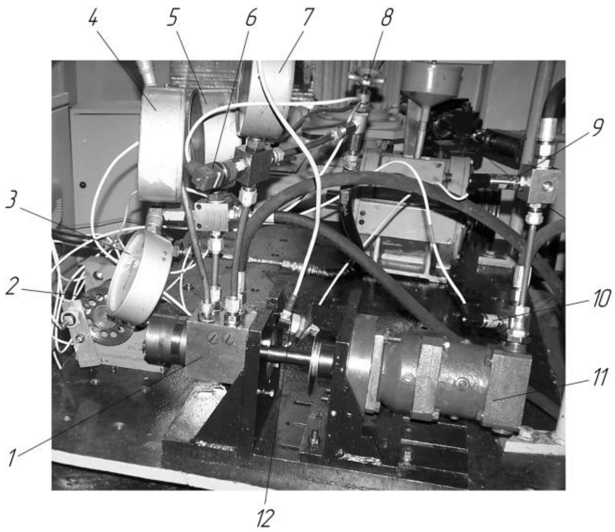


Fig. 6. Photo of the booth for testing the dosing pump during countercurrent action:
1 – steering control unit, 2 – flow sensor for working fluid , 3, 4, 5, 7 – pressure gauge , 6, 9, 10 – pressure sensors , 8 – throttle creating counter strike , 11 – hydromotor, which sets the control signal , 12 – sensor of the speed of rotation of the input shaft

The control and measuring system of the stand contains a sensor of angular velocity of the input shaft of the steering control unit. The sensor is made of frequency pulse type and for measuring the frequency of electric impulses in statics a low frequency frequency meter of grade Ch3-49 is used.

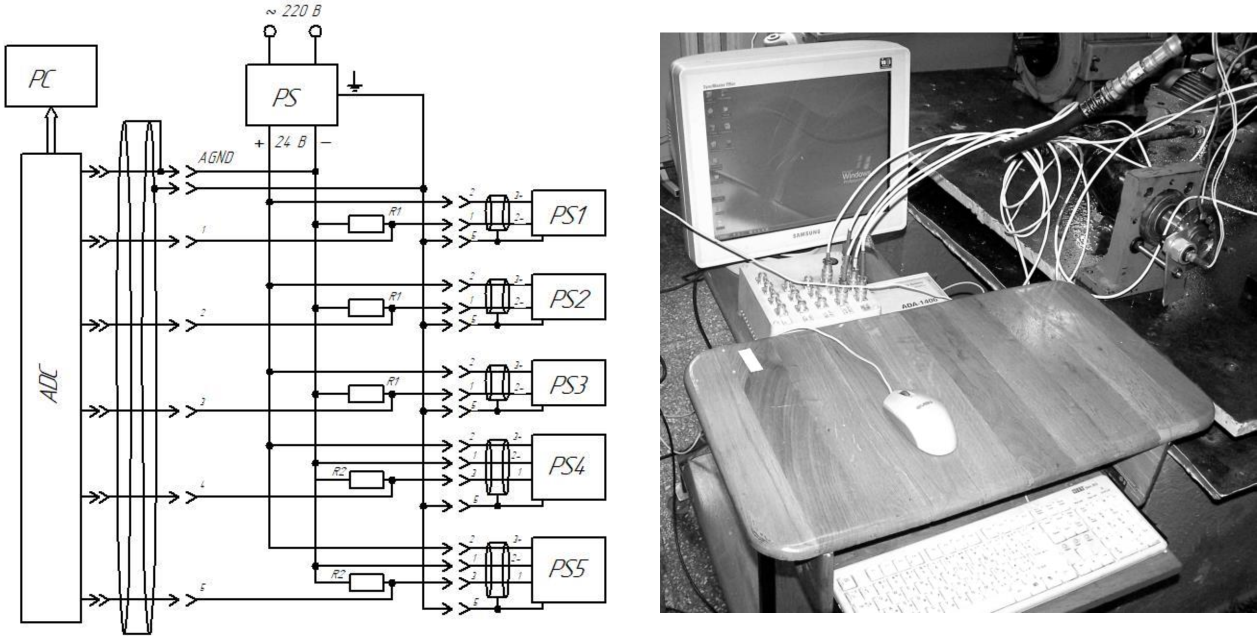
At the stand, the flow sensor *DF*, which allows you to control the flow of working fluid in different sections of the hydraulic system. In the scheme, this sensor is shown when measuring the flow of working fluid in the output channels of the steering control unit, which in the steering system is fed to the executive hydraulic cylinder under the action of the control signal.

For registration of dynamic signals, a computerized system for recording and processing the measured results of the studied parameters is used (Fig. 7) using a personal computer of a PC, an analog-digital converter of ADC and a program for measuring the results of the measurement. The block diagram of the system for recording the measurement results is shown in the figure (Fig. 7, a), and its photograph is on (Fig. 7, b).

Analogue electrical signals from pressure sensors are fed to the input channels of the analog-to-digital converter. An analog-to-digital converter ADA-1406, manufacturer of LLC "HOLIT Delta Systems, Ltd." (Ukraine, Kyiv) is used. Each input has individual settings for switching mode and transmission ratio.

The converter of continuous electric signals in the digital format itself is based on a 14-bit integrated circuit. In this case, sufficient performance (measurement frequency up to 350 MHz) and accuracy (error up to 3%) of dynamic signal transformation are provided. To export data to a personal computer, a parallel data channel is used to achieve high performance.

On the computer, the PowerGraph software was used to receive, record, store and process information, which provides individual setup and calibration of channels and allows the use of any signal measurement units. The program allows you to register a series of measurements in the form of independent data blocks, each of which has a continuous array of random channel data.



a) b)

Fig. 7. Computerized metering-recording system: (a) block diagram, (b) photography

Under constant parameters of the system, the values of the pressure on the corresponding sections of the hydraulic system, the speed of rotation and the flow of the working fluid, which analyzed the static characteristics of the steering system, are recorded on the readings of the devices.

During the study of the dynamic characteristics of the steering control unit, transient processes were recorded at different modes of its operation. Figure (8) shows an oscillogram that is registered at a rotation speed of the input shaft of 80 rpm and a counter load in the outlet ducts of the pump-dosing unit Δnn = 10 MPa.

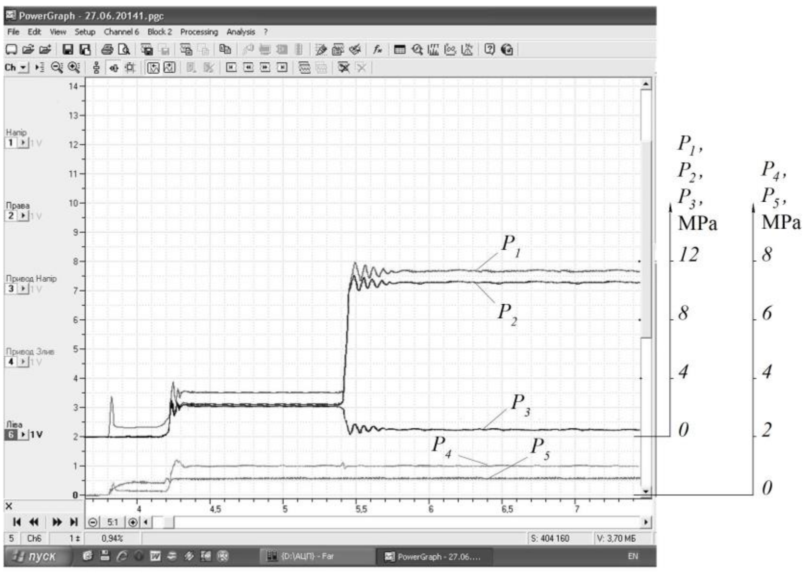


Fig. 8. Oscillogram of the steering control unit with a working volume of 160 cm^3 at the speed of rotation of the input shaft n = 80 rpm and countercurrent actions Δp = 10 MPa

The oscillogram shows the changes in the pressure P1, P2, P3, P4 and P5 in the corresponding sections of the hydraulic system of the steering control. The vertical axis on the oscillogram shows voltage, but pressure sensors of different types have different sensitivity and different zero points in accordance with the tare graphs. For convenience, on the left side of the oscillogram, the scales of the correspondence of the recorded signals with the pressure values are plotted.

For the organoleptic assessment of the quality of the pump-dosing device on the stand, the hydraulic motor GM1 is disconnected and instead of it the self-propelled steering wheel is installed, which allows obtaining an appropriate estimation of the operation of the pump-dispenser at different modes of its operation.

CONCLUSIONS

The method of experimental research of pump-dosing devices for systems of hydro-static steering control of special machines is offered. The peculiarity of this technique is that the load for the steering control unit is created in the form of a pressure difference in its output channels without the use of loading hydraulic cylinders.

The electrohydraulic circuitry of the stand was developed for the implementation of the proposed test method for steering control units. On the stand, a system for forming a control signal in the form of a rotation of the input shaft of the pump-dosing unit and a system for forming the load in the form of a pressure difference in its output channels is implemented. To form a counter or associated load, the stand is made with a variable structure. The characteristic of control and measuring equipment is given.

Such a performance of the stand allows to evaluate the quality of the operation of the pump-dosing, regardless of their working volume, and to determine the parameters of the steering control unit in conditions that correspond to different modes of operation of the steering system. In addition, it simplifies the analysis and research of the behavior of the steering control unit for a long time, which is not limited to the progress of the executive hydraulic cylinder of the steering system or the hydraulic cylinder loading system.

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