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EXPERIMENTAL STUDIES OF THE ADAPTIVE HUDRAULIC SYSTEM ON THE BASE OF THE DISTRIBUTION VALVE WITH PROPORTIONAL ELECTROHYDRAULIC CONTROL

Stable trend of the development of the hydraulic systems of mobile operation machines is the transition to the application of the regulated pumps and hydraulic devices with the proportional electric hydraulic control. In such hydraulic systems the correspondence of pumps capacity to the flow volume, consumed by the hydraulic motors as well as proportionality of the pressure value in the hydraulic system to the loading on the hydraulic motor or the most loaded of the several hydraulic motors is provided.

Mobile machines equipped with such hydraulic systems can efficiently operate with wide range of the changeable working tools, providing high quality of the work and loading of the machines during a year. Besides, the proportional control in the hydraulic systems of this type provides high accuracy of the operation execution and greatly improves the working conditions of the operators.

The paper considers the adaptive hydraulic system on the base of the distribution valve with proportional electrohydraulic control. Experimental stand for testing the adaptive hydraulic system was constructed. The hydraulic diagram of the distribution valve and the construction of the operation unit is presented. The distribution valve provides the possibility of the remote proportional electromagnetic control of the flow from the controller with the possibility of the stabilization of the hydraulic motors motion speed. Adaptive hydraulic system provides the possibility of the coordination of the hydraulic motors motion speed. The metrologic characteristic of the stand is given , which enables to control the value of the pressure in the hydraulic system, current and voltage values in the control lines, number of rotations of the hydraulic motor and registrate the dependences of the pressure values in the hydraulic system on the time if load changes. It was determined that the error of the flow value stabilization across the distribution valve does not exceed 6.8 %, in the studied range of the load change and the value of the flow changes proportionally according to the signal, sent from the controller. Regulation time in the hydraulic system on the base of the developed distribution valve did not exceed 0.83 *sec in the range of the pressure change* $p_n = (1.5 \dots 7.0)$ *MPa and the output of the pump* $Q_n = (0.05 \dots 0.5) \cdot 10^{-3}$ *m*^{3}*/sec.*

Key words: *adaptive hydraulic system, distribution valve, proportional electric hydraulic control, experimental stand, flow stabilization, stabilization error, regulation time.*

Introduction

Stable trend of the hydraulic systems of mobile operation machines is the transition to the application of the regulated pumps and hydraulic devices with the proportional electric hydraulic control. In such hydraulic systems the correspondence of pumps capacity to the flow volume, consumed by the hydraulic motors as well as proportionality of the pressure value in the hydraulic system to the loading on the hydraulic motor or the most loaded of several hydraulic motors is provided [1, 2].

Mobile machines equipped with such hydraulic systems can efficiently operate with wide range of the changeable working tools, providing high quality of the work and loading of the machines during a year. Besides, the proportional control in the hydraulic systems of this type provides high accuracy of the operation execution and greatly improves the working conditions of the operators [3, 4]. It should be noted, that the hydraulic systems of the base of the regulated pumps and electric hydraulic devices provide the operation with high hydraulic efficiency factor due to considerable decrease of non-productive expenditures of power in the operation cycle [5, 6]. Application of the hydraulic units with the electric hydraulic control creates wide possibilities for the application in the hydraulic systems of the mobile machines the programmable controllers. The usage of the controllers enables to coordinate the operation modes of the machine with variable external conditions and loading on the working tools as well as speed operation modes of two or more simultaneously working hydraulic motors. These possibilities allow to improve the efficiency of the machines operation [8].

Analysis of the studies carried out by the subject of the research

The scheme and the study of the adaptive hydraulic system on the base of non-regulated hydraulic motors, regulated hydraulic motor and controller is suggested and carried out in [9]. Adaptive hydraulic system is intended for the application in the mobile machine when the operations, requiring the coordination of the speed modes of several hydraulic motors, are performed. However the application of non-regulated pumps will be accompanied by considerable power losses in the process of the hydraulic motors speed modes regulation. Besides, the hydraulic system contains the distribution valves with electromagnetic relay control, that complicate the control in case of the alternating load. The control of speed of only one hydraulic motor is provided, this limits the functional possibilities of such adaptive hydraulic system.

In [10] the system of the hydraulic drives on the base of regulated pumps, sectional distribution and controller for the mobile machine is presented, the study of the system is carried out. The drawback of the suggested construction of the distribution valve is the lack of the proportional electric hydraulic flows control when two or more hydraulic motors are supplied from one regulated pump. Besides, the coordination of the speed values of the hydraulic motors motion is not provided in the system of the hydraulic drives.

In [11, 12, 13] the scheme of the mechatronic hydraulic drive on the base of the regulated pump, relay distributors, proportional hydraulic equipment and controller is presented. In the suggested hydraulic drive the possibility of the coordination of two hydraulic motors motion speed is provided. The drawback of such mechatronic hydraulic drive is the absence of the proportional electromagnetic control in the distributors. The function of the proportional electromagnetic control is performed by the introduction of the additional hydraulic units, that makes the hydraulic drive more complex.

The aim of the paper is to perform experimental tests of the adaptive hydraulic system on the base of the regulated pump, distributor with the proportional electric hydraulic control and sensitivity to loading.

Main material

Fig. 1 presents the hydraulic diagram of the stand for studying the adaptive hydraulic system on the base of the distribution valve with the proportional electric hydraulic control.

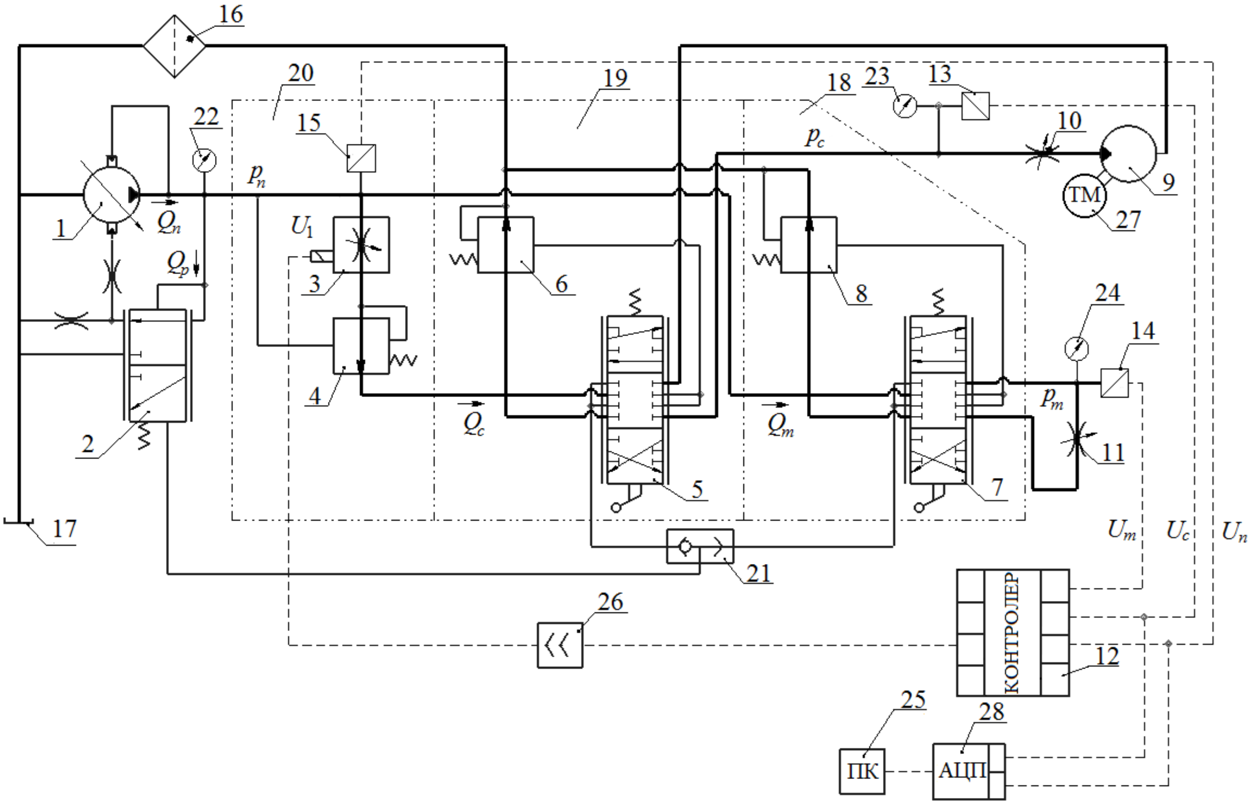

Fig. 1. Hydraulic scheme of the stand

The stand comprises regulated pump 1 with the regulator 2, distributor with the regulation unit 20, operating section 18, 19, hydraulic motor 9 with the tachometer 27, throttle valves 10, 11, controller 12, logic valve 21, filter 16 and tank 17. Pressure sensors 13, 14 and pressure gauges 22, 23, 24 are installed on the stand. Regulation unit 20 consists of the throttle 3 with electric magnetic control and differential pressure valve 4. Brake valves 8 and 6 and control valves7 and 5 are installed in each working sections 18, 19, correspondingly.

Hydraulic system, presented on the stand, operates in the following manner. Pump 1 directs the supply Q_s under the pressure p_s to the distributor, where it is divided into three flows Q_r, Q_s and Q_m. The flow Q_r provides the operation of the regulator 2. Flow Q_c passes across the regulation unit 20, working section 19, throttle 10 to the hydraulic motor 9, creating pressure p_c. Flow Q_m passes across the working section 18 and throttle 11, creating the pressure p_m. The value of the flow Q_c depends on the opening of the working window of the throttle 3 and opening of the working window of the control valve 5. Opening value of the working window of the throttle 3 is determined by the signal U_1, arriving from the controller 12. Opening value of the working window of the control valve 5 is determined by its location relatively the housing and is set by the operator in the process of study. Value of the flow Q_m depends on the value of the working window opening of the control valve 7, determined by the operator on the condition that in the process of study pressure value p_m at the throttle 11 input exceeds the value of the pressure p_c at the input into the throttle 10.Values of pressure p_c та p_m are set by the throttles 10 and 11 correspondingly. Logic valve 21 provides the supply of the working fluid under the pressure p_m to the regulator 2. This enables to maintain at the pump input the pressure p_m value of which is proportional to the value of pressure p_m at the throttle input 11. Value of the flow Q_c, arriving to the hydraulic motor 9 is possible to adjust by means of the controller 12, forming the control signal U_1 sent to the throyyle 3 with electric macnetic control. Value of the signal U_1 may be set by the program, in the form of the dependence on the time or in the form of the dependence on the values of the pressure p_n, p_c, and p_m, which send signals U_n, U_c та U_m at the inputs of the controller 12 across the pressure sensors 15, 13 and 14. The presence on the stand of the hydraulic motor 9 with the tachometer 17 enables in static modes to record the rotation frequency of the hydraulic motor shaft and assess the value of the flow Q_c, passing across the working section 19. Analog-to-digital converter 28 in the complex with the PC 25 allow to fix the dependences of the pressure values on time if the settings of the throttles, 3 10 and 11 change at the moment of the stand start.

Technical characteristics of the stand:

1.	Nominal supply of the pump	$1\cdot10^{-3}$ m^3/s;
2.	Nominal pressure of the pump	16 MPa;
3.	Regulation range of the pump supply	(0,05…1,0)· 10^{-3} m^3/s;
4.	Separation capacity	15 μ;
5.	Pressure measurement accuracy	±1,5%;
6.	Accuracy of the hydraulic motor frequency measurement	±1,0%;
7.	Voltage measurement accuracy	±0,5%;
8.	Current measurement accuracy	±0,5%;
9.	Temperature measurement accuracy	±0,5°C.

Fig. 2 presents the construction of the working section of the distribution valve with the proportional electric hydraulic control.

The section comprises the housing 1, where the control valve is located, it is put into operation by means of the handle 3. Control valve is fixed only in the position “neutral”. If the control valve moves leftward or rightward its operating windows open. By means of changing the position of the control valve it is possible to control proportionally the value of the flow rate of the valve, passing across the distribution valve. Brake valve 4 allows to perform the control of the load on the hydraulic motors and provides the drain of the working fluid from the hydraulic motor across the chamber 9. Regulated throttle 5 is put into motion by the proportional electric magnet 6, which obtains the control signal from the controller. The value of the flow across the distribution valve changes proportionally to the value of the control signal. Differential pressure valve 7 provides the stabilization of the working fluid flow value across the distribution valve if the load changes at the hydraulic motor. The pump, supplying the working fluid across the distribution valve is connected to the channel 8 and the hydraulic motor – to pipes 10.

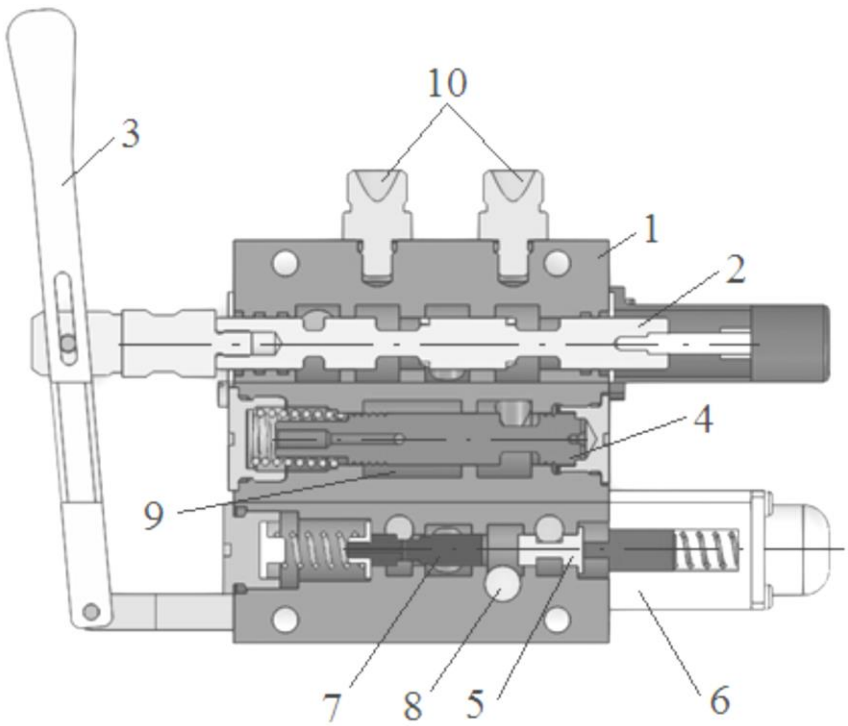

Fig. 2. Construction of the distribution valve section

Fig. 3. presents the photo of the distribution valve, installed on the stand.

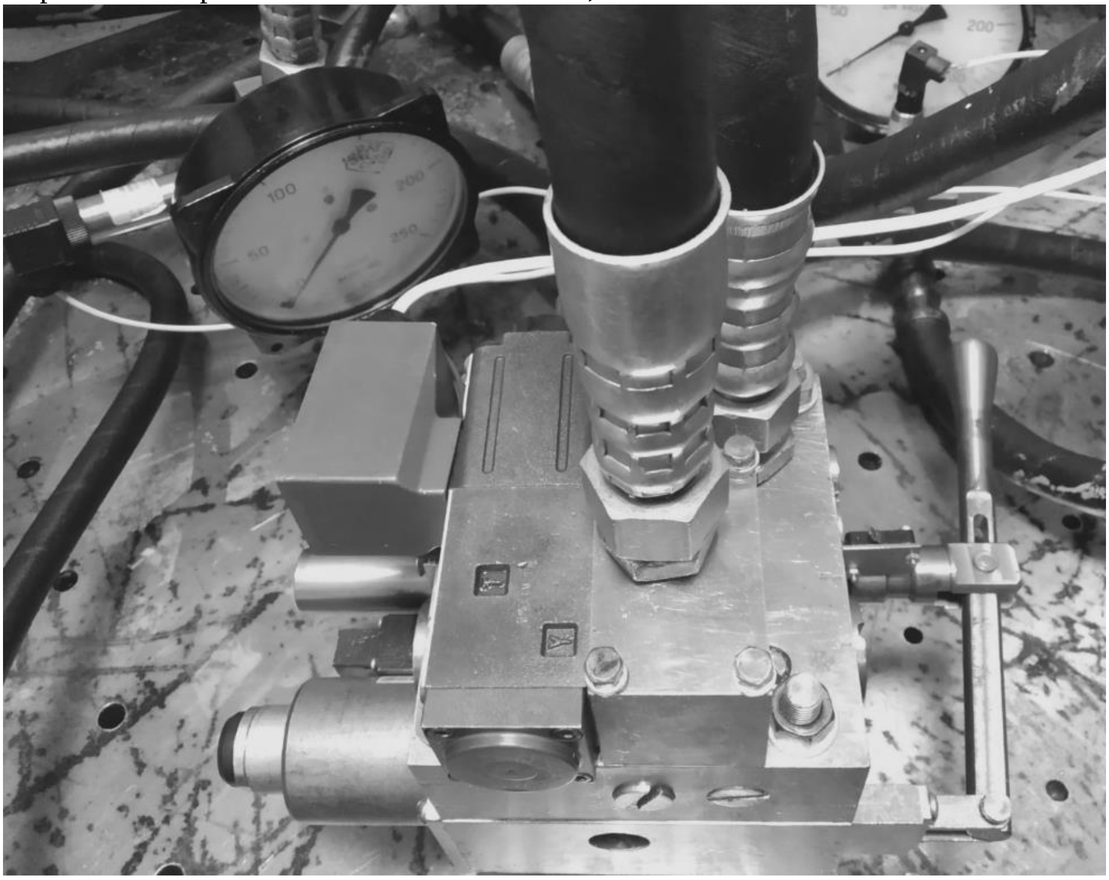

Fig. 3. Photo of the distributor on the stand

In the process of studies the dependence of the flow Q_c value across the distributor on the value of the pressure at the input of the throttle is determined (see Fig.1). The studies are performed for two values $Q_c = 0{,}15 \cdot 10^{-3}$ m^3/sec та $Q_c = 0{,}75 \cdot 10^{-3}$ m^3/sec. Setting of the value Q_c was performed on the base of the control of the value of the number of rotations n of the hydraulic motor 9 by means of the tachometer 27. Value of the flow Q_c was determined as

$$Q_c = q \cdot n / \eta_0$$

where $q = 50 \cdot 10^{-6}$ m^3 – working volume of the hydraulic motor; $\eta_0 = 0{,}96$ – volumetric efficiency factor of the hydraulic motor..

Fig. 4. presents the dependence $Q_c = f(p_c)$ in the range of the pressure $p_c = (1{,}0 \ldots 6{,}5)$ MPa change.

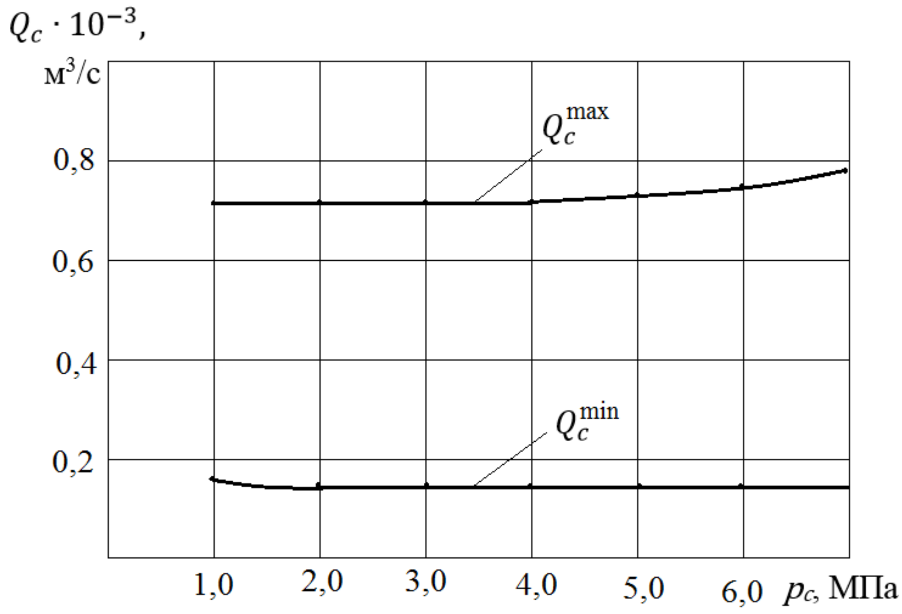

Fig. 4. Dependence of the flow Q_c across the distribution valve on the value of the pressure p_c at the input of the throttle

With the change of the pressure p_c the value of the flow Q_c changes relatively the set value. The deviation value of the flow Q_c from the set value was evaluated by the stabilization error value of the according to the formula:

$$A = \frac{Q_c^{max} - Q_c^{min}}{Q_c^{min}} \cdot 100\%,$$

where Q_c^{max}, Q_c^{min} – maximum and minimum value of the flow at the boundary values of p_c from the considered range. At setting $Q_c = 0{,}75 \cdot 10^{-3}$ m^3/sec stabilization error value is $A = 5{,}5$ %, and at setting $Q_c = 0{,}15 \cdot 10^{-3}$ m^3/sec – $A = 6{,}8$ %.

Fig. 5. presents the dependence of the flow value Q_c on the value of voltage U_1, on the electric magnet of the regulated throttle 3. Value U_1 is formed and maintained by the controller at a stable level in the period of determination of the rotation frequency value of the hydraulic motor 9 shaft . The value of the rotation frequency of the hydraulic motor shaft at U_1 change in the range from 7 V to 11 V with the change step of 1 V was determined. The value of the flow Q_c across the working section of the distribution valve was determined by the values of the rotation frequency of the hydraulic motor shaft. The study was carried out for two pressure p_n values equal 2.0 MPa and 4.0 MPa.

The distribution valve provides the proportional change of the flow Q_c value n case of the change of voltage U_1 value at the electric magnet of the regulated throttle. With the increase of the pressure p_n value at the output of the pump the nonlinearity of this dependence increases.

Fig. 6 presents the dependence of the pressure p_n at the output of the pump on the time of its start. Oscillographic testing was carried out at the connected control valve 5 and disconnected control valve 7. The throttle 10 was set for the creation of the static pressure p_n=5,0 MPa and the regulated throttle 3 was set on the flow value $Q_c = 0{,}5 \cdot 10^{-3}$ m^3/sec. In the process of study the pressure p_n was measured by the pressure sensor 15 and was recorded on the personal computer 25. The time of transient process at p_n=5,0 MPa and $Q_c = 0{,}5 \cdot 10^{-3}$ m^3/sec is 0,7 sec .

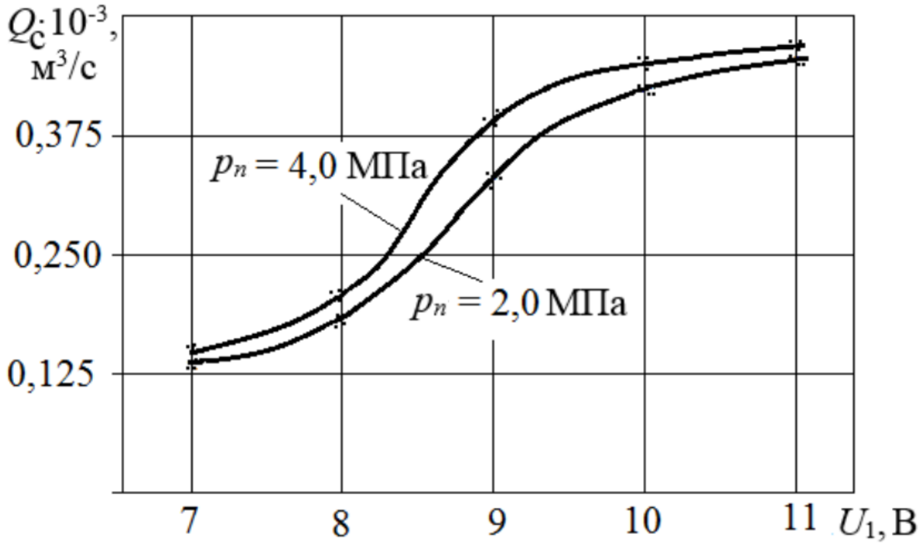

Fig. 5. Dependence of the flow value Q_c across the distribution valve on the voltage value U_1

Fig. 6. Dependence of the pressure value p_n at the input of the pump on the time during the start

Fig. 7. presents the dependences of the pressures p_n (at the output of the pump) and p_c (at the throttle 10 input) on the time during rapid decrease of the value of the throttle 10 opening area.

Pressures p_n and p_c were measured by the sensors 15 and 13, they were recorded on the personal computer 25. The value of the throttle 13 opening was set for the pressure p_c=1,0 MPa and the value of the throttle 3 opening was set on the flow $Q_c = 0{,}5 \cdot 10^{-3}$ m^3/sec. At a sudden reduction of the opening of the throttle 10 window pressures p_n and p_c increase. The relation in the stable mode $p_n = p_c + 1{,}6$ MPa that corresponds to the setting of the regulator 2 of the regulated pump 1, remains. Time of the transient process is $t_p = 0{,}83$ sec.

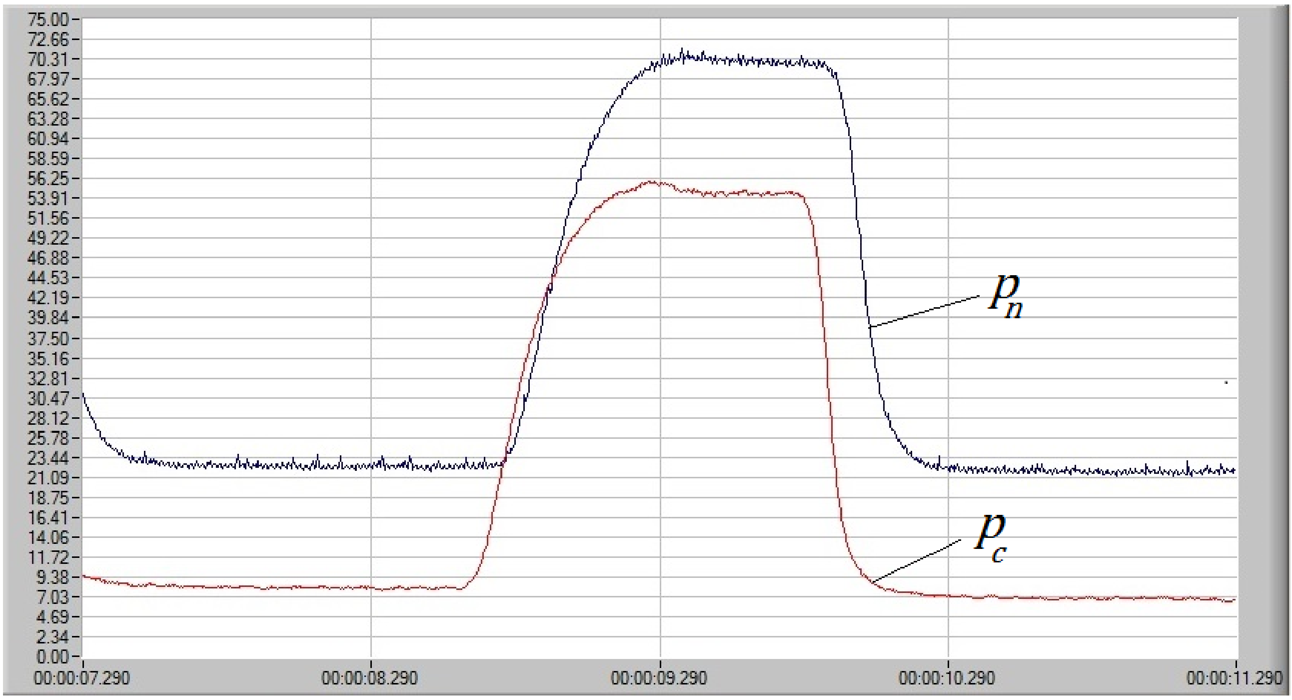

Fig. 7. Dependences of the pressure values p_n and p_c on the time in case of the working window of the throttle decrease at the output of the distribution valve

Conclusion

1. The research, carried out, prove the serviceability of the developed scheme, construction of the distribution valve with the electric magnetic control and the hydraulic system, constructed on its base.

2. In static modes the proportional flow regulation from the pump to the hydraulic motor is provided in accordance with the value of the signal, sent from the controller. If the pressure value in the hydraulic system changes, the flow values is maintained close to the set value. Flow stabilization error at pressure changes $p_c = (1{,}0 \ldots 7{,}5)$ MPa did not exceed $A \leq 6{,}8$ %.

3. In the process of the dynamic studies it was determined that at the start of the pump and sudden change of the throttle setting at the output of the hydraulic system in the range of the pressure change $p_n = (1{,}5 \ldots 7{,}0)$ MPa and pump output $Q_n = (0{,}05 \ldots 0{,}5) \cdot 10^{-3}$ m^3/sec the time of the regulation in the hydraulic system did not exceed $t_p \leq 0{,}83$ sec.

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