Device for automatic pressure regulation in a chamber with a liquid technological medium isolated from the pressure source

E V Pashkov*, V P Polivtsev, V V Polivtsev and A A Vozhzhov
Sevastopol State University, Sevastopol, Russia
*pashkov@sevsu.ru

Abstract. The functional capabilities of traditional devices for automatic pressure control of various liquid media are analyzed. A diagram of a device for smoothly changing the pressure of a liquid process medium in a chamber with a built-in metal bellows hydraulic displacer, the cavity of which is connected by a pressure-drain pipeline with built-in proportional flow regulator and a shut-off valve with a pressure source for the liquid working medium, is considered. Smooth pressure change is ensured by changing the switching frequency of the shut-off valve.

1. Introduction
This technical solution relates to systems for automatic pressure control of liquid working media using electrical means and can be used as part of test and industrial installations with large-volume and high-pressure chambers during research and implementation of various technological processes in chemical, food, etc. industries.

A device for regulating the pressure in the chamber [1] is known, containing a pressure source, a supply line and a pressure relief line with a pressure regulator built into them and a three-line two-position distributor electrically connected to the output of the control unit, the input of which is electrically connected to the control sensor pressure in the chamber. The electrical signals coming from the pressure sensor are compared with the preset signal values proportional to the preset pressure, as a result of which the control unit generates control pulses for the valve, which connects the chamber with a preset frequency alternately to the supply or reset line.

The disadvantage of the device is the inability to automatically change the pressure value in the process of filling or emptying the chamber according to a given law, as well as low control accuracy due to the large discreteness, i.e. spasmodic operation of the distributor, the shut-off element of which, when the control electrical signal is applied or disconnected, can occupy only two extreme positions, which ensure full opening or complete shutdown of the supply and pressure relief line, which does not allow for a smooth change in flow rate and, consequently, pressure.

It is known "A device for automatically regulating the pressure in the power cylinder of a hydraulic press" [2], which contains a pump connected by a pressure line with the cavity of the power hydraulic cylinder, a pressure regulator in the form of a plunger hydraulic cylinder with a control mechanism in the form of an electric drive with an adjustable frequency of rotational movement, having It includes a mechanical transmission based on a reducer and a rotary-to-translational transducer of the “screw-nut” type, hydraulic valves with electromagnetic control and a pressure sensor electrically connected to the corresponding outputs and input of the control unit.
The disadvantage of this device is both low control accuracy and the inability to smoothly change the flow rate, and therefore the pressure, due to the use of a pressure regulator for moving the plunger of an electric drive with a mechanical transmission based on a gearbox and a mechanical converter of rotary motion into translational motion of the "screw-nut", characterized by a high threshold of sensitivity due to losses to overcome friction and clearances (backlashes) in the kinematic pairs of transmission.

In addition, the presence of a controlled electric drive in the device significantly increases its size and weight, complicates the design of the control unit, and requires additional software, which differs from the use for controlling hydraulic valves.

In traditional high-pressure sources based on pumps, as a rule, a liquid working medium is used in the form of machine (industrial) oil. In cases where the liquid technological medium in the chamber differs in chemical composition and physical properties from the liquid working medium, it is necessary to use special separators of liquid media, which can be used, for example, metal bellows hydraulic displacers.

Hydraulic displacers refer to hydraulic equipment, namely to volumetric hydraulic machines, and are designed to transfer energy from one liquid (working) medium to another liquid (technological) medium without contacting each other, for example, in hydraulic drives of industrial technological equipment with special volumetric sealed working chambers with specified pressure values, ensuring the implementation of the corresponding technological process [3,4,5].

Reducing the energy losses of the flow of the working medium in order to ensure the required accuracy of its transformation into the energy of the technological medium is achieved using multi-bellows hydraulic displacers, the design of which is characterized by the presence of several bellows [6,7].

2. The problem statement
The problem is to increase the accuracy of automatic regulation of the pressure value of the liquid technological medium in the chamber, which differs in chemical composition and physical parameters from the liquid working medium of the pressure source, as well as to ensure a smooth rate of its change and to simplify the design of the device for its solution.

3. Results
Device for automatic regulation of the pressure of the liquid medium in the chamber (Fig. 1) contains a pump 3 with a drive motor 2, connected by a pressure line 4 with a sealed cavity of a metal bellows displacer 10, attached to the bottom of the chamber with a large volume V1 and high pressure nine.

A proportional four-line three-position hydraulic distributor (PGR) 6 with one plugged output line and a fast-acting shut-off valve (OC) (two-position two-way hydraulic valve) 7 with a high response time are built into the pressure line, the response time of which is shorter than the response time of the PGR.

The control unit 11, made with the ability to regulate the magnitude and frequency of the output signals, is electrically connected to the electromagnets of the PGR and OK, as well as to a pressure sensor 8, for example, analog, built into the chamber cavity.

Before starting operation, PGD 6 and OK 7 are in a closed state, as shown in Fig. 1, chamber 9 is closed with a sealed lid and filled with a pipeline with a shut-off valve (not shown in the figure) with a process liquid medium under normal pressure through the hole in the lid until all air is removed from it.

The process of increasing in the pressure chamber occurs in the following sequence.

The electrical signal generated at one of the outputs of the control unit 11 starts the drive motor 2 of the pump 3 installed in the container 1 with a liquid working medium, for example, machine oil.

Then, the control unit generates control electrical signals, which, coming from its other outputs to the corresponding inputs of PGR 4 and OK 5, cause them to switch to the left position, i.e. opening, providing the passage of a liquid working medium under pressure into the cavity of the bellows 10,
causing its elastic deformation (tension) in the axial direction and compression, i.e. increasing the pressure to the set value of the liquid process medium in the chamber. The rate of pressure change depends on the flow rate provided by the flow area of the PGR and OC channels. The change in pressure in the cavity of the chamber 9 is controlled by the pressure sensor 8, which constantly generates signals, for example, in the form of a voltage proportional to the value of the changing pressure coming from its output to the input of the control unit 11.

**Figure 1.** Diagram of a device for automatic regulation of the pressure of a liquid medium in a chamber
In the control unit, the current pressure value is compared with the specified program value, and the generated mismatch signal arriving at the input of the PGR 6 causes it to operate in order to change the flow rate of the working fluid, which determines the rate of pressure change in the bellows and chamber cavities, i.e. making it smoother.

If the discreteness of the PGR operation does not allow to ensure the specified rate of change in the flow rate with the required accuracy, the control unit 11 generates electrical control signals that are received with a certain frequency at the input of OK 7, transferring it from the standby mode to the pulse mode of operation, which provides multiple changes in the throughput section of the channel for the passage of the liquid working medium.

The discreteness of the change in its flow rate is reduced, as a result of which a smoother achievement of the specified pressure value in the chamber with greater accuracy is ensured, after which the control unit turns off the pulse mode of operation of the shut-off valve and generates a signal that causes the OK to switch to the right position, and the PGR to the middle position, i.e., the pressure line 4 is closed.

To reduce the rate of pressure change in the cavities of the bellows 10 and chamber 9, or to completely remove it, according to signals from the control unit, the OK switches with a certain discreteness to the left position, and the PGR - to the extreme right position, connecting the pressure line 4 with the drain line 5, through which the liquid working medium enters the container 1.

When the supply of a liquid working medium into the cavity of the bellows 10 is turned off, it is compressed under the action of the pressure of the process medium, as well as under the action of the elastic deformation energy accumulated in it during stretching, thereby returning to its original free state, displacing the liquid working medium into the container 1.

As in the case of filling, the rate of discharge of the working liquid medium and the pressure of the process liquid in the chamber cavity are controlled by the sensor 8, the signals from which are sent to the control unit, which, after processing them, generates the corresponding control signals for PGR and OC.

The absence of a pressure drop in the cavity of the chamber and the bellows eliminates the deformation of the latter in the radial direction.

The number of bellows hydraulic displacers built into the chamber, depending on the pressure drop of the process liquid medium in the chamber of volume \( V_1 \) and the selected dimensional parameters of the bellows 10, is determined as follows.

The compression ratio of the technological liquid medium in the chamber [8]

\[
\beta = \frac{\Delta V_1}{V_1} \Delta p,
\]

where \( \Delta V_1 \) is the change in the volume of the liquid process medium in the chamber; \( \Delta p \) - change (difference) in pressure of the liquid technological medium in the chamber, from where

\[
\Delta V_1 = V_1 \Delta p \beta.
\]

(Note: for water \( \beta = 47.5 \times 10^{11} \text{ Pa} \)).

The volume of the liquid process medium \( \Delta V_2 \) displaced by one bellows of diameter \( d \) and length \( L \) in the free state, with a working stroke \( \Delta L = 0.1 \) L, which is 10% of its length in the free state,

\[
\Delta V_2 = \left( \pi d^2 / 4 \right) \Delta L = 0.1 \left( \pi d^2 / 4 \right) L.
\]

From the above, it follows that the required number of bellows

\[
n = \frac{\Delta V_1}{\Delta V_2} = \frac{12.7 \beta V_1 \Delta p}{(d^2 \text{ L})}.
\]

The resulting value of \( n \) should be rounded up to the nearest whole number.

4. Conclusion
A comparative analysis of the proposed device and known technical solutions shows that the use of a proportional valve, which implements a given fluid flow rate, in combination with a high-speed shut-
off valve operating periodically in a pulse mode with a relatively shorter response time than a proportional valve, i.e. with a higher speed, allows you to reduce the discreteness of the change in flow rate, and therefore change the rate of filling or emptying the chamber cavity and the discreteness of the change in it.

References
[1] A device for regulating the pressure in the chamber: a. from USSR No. 1053075, IPC G05D 16/20 / Yu.N. Kabanov, G. D. Vladimirtsev, V.K. Semenova; publ. 11/07/1983.
[2] Device for automatic regulation of pressure in the power cylinder of a hydraulic press: RF patent No. 2278026, MPK V30V 15/22 / Yu.M. Osokin, V.A. Yunyshev; publ. 20.06.2006.
[3] GOST 17752 - 81 (ST SEV 2455 - 80). Volumetric hydraulic drive and pneumatic drive. Terms and definitions (with Amendments No. 1,2).
[4] Sveshnikov V.K. Machine hydraulic drives: a reference book / V.K. Sveshnikov. - 5th ed., Rev. and add. - M.: Mechanical Engineering, 2008.- 640s.
[5] Hydraulics, hydraulic machines and hydraulic drives: a textbook for mechanical engineering universities / TM. Bashta [and others]. - 2nd ed., Rev. - M.: Mechanical Engineering, 1982.- 423 p.
[6] Pashkov E.V. Multi-bellows hydraulic displacers of hydraulic drives of industrial technological equipment / E.V. Pashkov, V.P. Polivtsev // Scientific journal "Automation and measurements in mechanical engineering", No. 3 (7), 2019, pp. 98-105.
[7] Pashkov E.V. Combined multi-bellows hydraulic displacer / E.V. Pashkov, V.P. Polivtsev, M.I. Kalinin, V.V. Polivtsev // Collection of scientific papers "Bulletin of modern technologies"", No. 2 (14), 2019, pp. 15-20.
[8] Vilner Ya.M., Kovalev Ya.T., Nekrasov B.B. Reference book on hydraulics, hydraulic machines and hydraulic drives. Ed. B.B. Nekrasova. Minsk, Higher. School, 1976. - P.12, section 1.2.