IOP Conf. Series: Materials Science and Engineering **779** (2020) 012003 doi:10.1088/1757-899X/779/1/012003

The implementation of digital program control in hydraulic actuators of hydraulic structures

I Zyubin[1], N Kushnir[1], A Akinfiev[2] and A Sinitsyna[2,3]

[1]Moscow Power Engineering Institute
[2]Bauman Moscow State Technical University

[3]E-mail: sin.anastasia23@gmail.com

Abstract. The problems of controlling the gates of hydraulic structures from the point of view of modernizing current systems and expanding their capabilities are considered. A variant of the modernization of a discrete directional control valve is presented, which ensures the further implementation of a digital system for controlling the speed and position of the hydraulic control regulating element of hydraulic structure.

Introduction

In the territory of the Russian Federation there are an extensive number of hydraulic structures, providing a rated culvert operation through canals and reservoirs. Most of them were built in the period from the early to mid-20th century [1].

At many installations, a hydraulic actuator is used to maneuver the different mechanisms (gates, locks, flood hatches, etc.) [2–4]. However, due to the significant age of the facilities, hydraulic actuator equipment installed at the facilities does not meet the current level of technology development and limits the potential for safe operation of the installation.

The main hydraulic equipment is controlled by discrete control valves [5–6]. Using these valves allows controlling the process only in start-stop mode. The simplicity of the drive design and its relative cheapness in this case lead to a number of operational difficulties, for example, complicates the process of synchronizing the operation of hydraulic motors. At current installations, hydraulic motors are synchronized by a synchronous-tracking mechanical system connected to drain valves [7].

Such systems are difficult for settings and require frequent maintenance, which ultimately leads to an increase in the cost of the lock system as in general, as a single design.

The current trend in the development of hydraulic drive systems is the use of servo drives, which are controlled by electronic modules [8]. The synchronization of the hydraulic motors in this case will be carried out using the proportional control valve. Also, it becomes possible to regulate the speed of movement of the actuating element, as well as to apply the laws of movement selected by the adaptive control system when automatically taking into account external factors (for example, the current operating mode of hydraulic structures and the transition process in the after bay of the hydroelectric power station).

However, despite the advantages of such systems, they have a number of significant disadvantages:

a) High starting cost: caused by the requirements for high-precision manufacturing of hydraulic equipment with proportional control;

IOP Conf. Series: Materials Science and Engineering **779** (2020) 012003 doi:10.1088/1757-899X/779/1/012003

b) Special requirements for the cleanliness of the internal holes of hydraulic equipment and pressure fluid: caused by small radial clearances in hydraulic equipment.

c) The need for highly qualified specialists involved in the installation and operation of the system. It is determined by the ability of stuff to make settings of drive elements and to detect the malfunctioning on time.

The disadvantages listed above are the main limiting factor for the use of proportional control servo hydraulic systems. According to [9], high cost is the main deterrent to the use of proportional equipment in Russia.

At the same time, special requirements for the pressure fluid and the corresponding regeneration systems, makes the use of valves in the current hydraulic systems complicated. Modernization of the hydraulic system requires significant financial and time costs. One of the options for minimizing the amount of work and improving the quality of control is the use of a numerical control electro hydraulic valve developed at the Department of Hydromechanics and Hydraulic Machines in Moscow Power Engineering Institute as part of the existing hydraulic system.

Methods

When developing the device, one of the ways to reduce the cost of manufacture and operation was considered the reduction of the requirements for the precision manufacturing a pair of spool-sleeve. According to the [10], the transition from a radial clearance of 5 μm (typical for proportional spool pairs) to radial clearance of 20 μm (corresponding to discrete valves) reduces the cost of manufacturing the control valve trim in 2 times. The developed part is based on the trim from a standard traditional discrete control valve. Its conversion to a proportional-control control valve is carried out by modernizing the spool displacement drive. As an electromechanical transducer, the stepper motor paired with a screw-and-nut transmission is used in this control valve. The block diagram of the control valve is shown in Fig. 1.

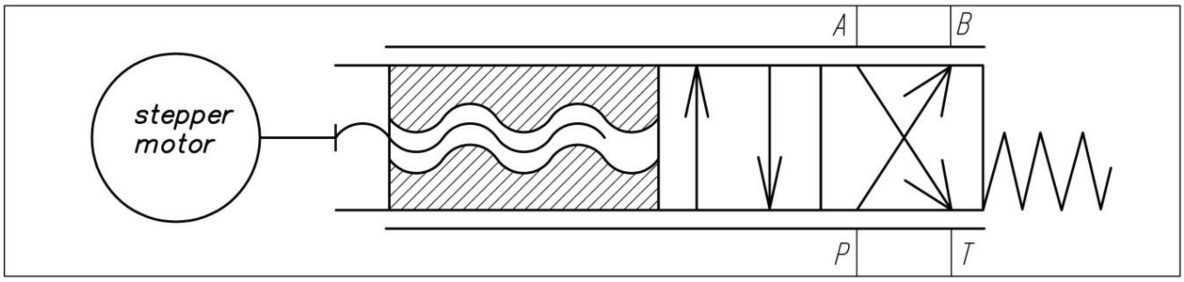

Fig.1. The block diagram of the control valve

Correction of the operating characteristics of the control valve is carried out through the use of a specialized numerical control system. By changing the relationship between the input control signal and the movement of the spool, an automatic linearization of the flow characteristic is performed.

The principle of operation of the developed control valve is described in more detail in [11], [12].

The use will make it possible to integrate the proportional control of the operating mechanisms of hydraulic structures with the ability of adaptive control, or according to specially developed algorithms, as well as with using the modern numerical control systems [13–14]. Due to the use of the trim from the discrete control valve, there is no need for a high quality pressure fluid, since the spool-sleeve pair in such a valve is made with a large radial clearance.

To check the possibility of using control valves as part of hydraulic actuation systems of various hydraulic structures, as well as for the assembly work and testing, a specialized test bench was created at the Department of Hydromechanics and Hydraulic Machines.

The test bench is based on a serial hydrodynamic tray (Fig. 2.). The gate valve is moved due to a double-acting hydraulic cylinder (HC1), which, in one's turn, is controlled by a proportional control valve. The position of the gate valve is determined using an encoder. A number of ultrasonic level sensors are located throughout the tray.

When the gate valve is moving in the tray, a non-steady flow mode occurs. The location of the level sensors is selected to provide a record of the parameters of the passage of wave processes along the tray in time at different points in space, and the sensor readings will be used to operate the control system in automatic mode.

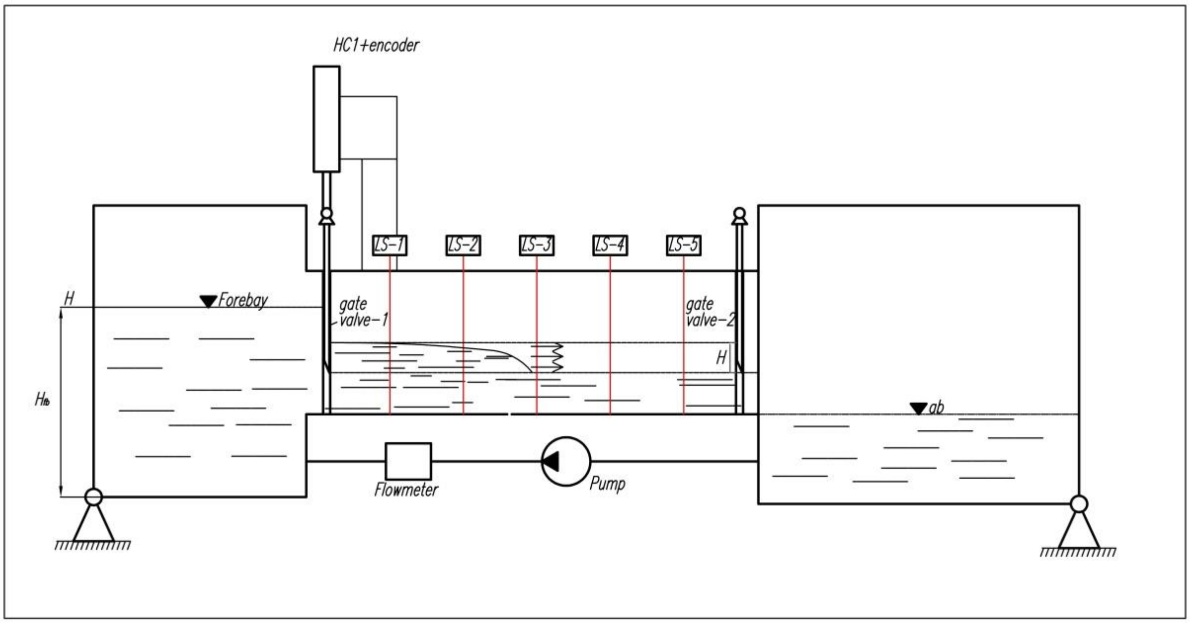

Fig.2. The structural scheme of the test bench

The test bench management system involves working in automatic mode to solve the following application tasks:

a) Maintaining a constant level in the tray when the external factors are changing.

b) Mitigation of transient wave processes in the tray.

c) Deliberate creation of wave processes in order to demonstrate the capabilities of the system.

The work of the test bench in automatic and semi-automatic modes is provided with the help of a specialized control system (Fig. 3). The control system of the test bench consists of two subsystems — a subsystem for collecting and processing data from level sensors and a subsystem for controlling the servo drive and the stepper motor of the control valve, in particular. The examples of using the stepper motors in hydraulic and pneumatic systems are given in [15–16].

In automatic mode, the control system takes data from level sensors, processes them, and determines the direction of the wave process and its amplitude. Then, after analyzing the speed, acceleration and coordinate of the front of the wave, it sends a command for the exact displacement of the gate in relate to the initial state.

All the necessary parameters of the system are recorded on the memory card, and also displayed on the display of a personal computer for the possibility of processing them.

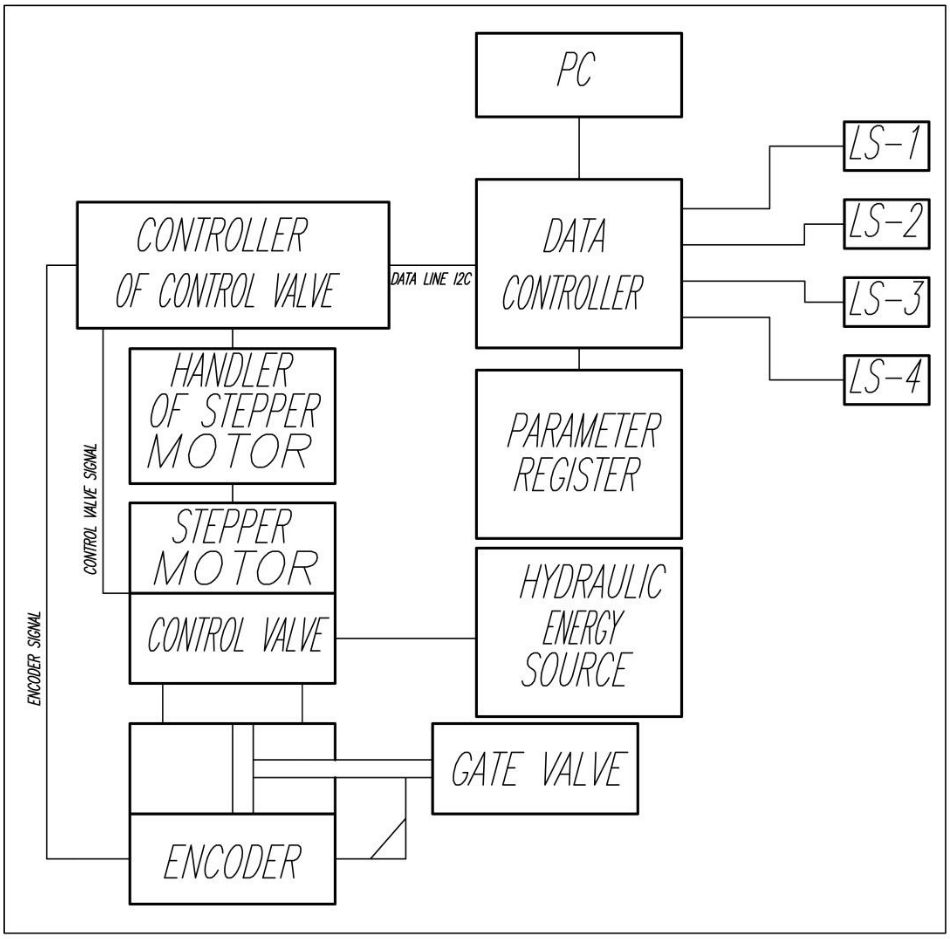

Fig.3. The structural scheme of the digital control system of the test bench

Results

The capabilities of the test bench allow not only to analyze the control modes of hydraulic structures, but also to carry out experiments to study the use of hydraulic actuators with adaptive operation algorithms. By installing the models of hydraulic power system of various structures on the test bench, it becomes possible to emulate their work in laboratory conditions, creating various environmental disturbances. This will allow developing of operation algorithms for the control system, being applied to a specific object.

Separately, one should take into account the possibility of an empirical analysis of the operation of energy-generated devices, in particular, models of wave power stations. The possibility of obtaining regulated wave processes in the channel allows the comparing of the efficiency of various designs of wave power stations as renewable energy sources.

An experimental research of a servo drive with a modified control valve and controller was carried out by the sine sweep method, or by the sine method. Using this method, a Lissajous figure is drawing for which the output signal from the encoder is plotted along the Y axis, which is proportional to the movement of the output rod of the hydraulic actuator, and the displacement along the X axis is proportional to the input signal. The input signal for the actuator in the research is a sinusoidal signal from the master frequency generator. The ellipse for the actuator under study at an input signal frequency of 7 Hz is shown in Fig. 4. The relative coordinate of the displacement of the rod of cylinder of hydraulic actuator is plotted along the X axis, and the relative value of the input signal is plotted along the Y axis. Relative values are obtained as the ratio of the current value to the rated value.

In Fig. 4 it is clearly shown that the practical effect of the extended deadband during control valve modernization is weak and the algorithm used to linearize the control valve characteristics to compensate for large clearance in the sleeve-spool pair works satisfactorily - the figure does not have typical shape distortions in the form of "corners" and "steps".

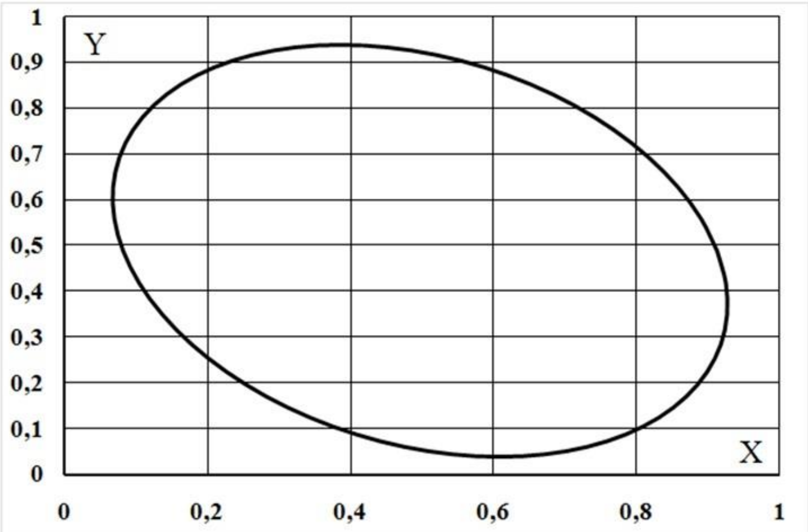

Fig. 4. Graphical view of the sine wave

The cutoff frequency of an actuator with a modified control valve is 10 Hz. The use of the FESTO standard proportional directional control valve, model MPYE-5-010-B within the framework of the servo drive under consideration, allows achieving a cut-off frequency of 25 Hz.

A further increase of the cutoff frequency during conversion of the control valve is connected with an increase in the stepper motor capacity and an increase in its size. In [17], the problem of placing the overall motor was solved due to the the placing of the actuator at the angle of 90 degrees to the axis of movement of the spool, therefore reducing the axial dimension of the control valve, but it does not solve the problem of a general increase in the mass of the device.

Discussions

It should be noted that when using a control valve in control systems of hydraulic structures, the need for good dynamic qualities is not always justified, since the processes take quite long time and relatively high positioning accuracy is not required in comparison with, for example, actuators of metal-cutting machines. Laboratory analyzes did not identify the benefits of a faster hydraulic device. However, for an objective determination of a sufficient response time, an additional analysis of the operation of real hydraulic systems is required.

Thus, it can be noted that the developed control valve will significantly improve the quality of control of the regulating object of the hydraulic structure, and a designated test bench will allow us to accumulate empirical knowledge that will be the basis of accurate calculations of the control system operation algorithms.

List of reference

[1] O.A. Astrakhantseva, V.I. Golubev, V.V. Fedenkov. The use of variable-frequency control of the gate of the water galleries of the Moscow channel gateway and the analysis of dynamic characteristics // Hydraulic machines, hydraulic drives and hydropneumatic automation / XX All-Russian scientific and technical conference of students and postgraduate students. Moscow Power Engineering Institute, December 7, 2016: a collection of materials and reports. — M .: MEI Publishing House, 2016. — 170p.

[2] Sosnovsky, N., Ganieva, D. Mathematical modeling and analysis of the electrohydraulic actuator with the throttle control (2019) IOP Conference Series: Materials Science and Engineering, 589 (1), article № 012016.
[3] Pilgunov, V., Efremova, K. Ring-shaped fluorescence of mineral oil on the front edge of the choke coil (2019) IOP Conference Series: Materials Science and Engineering, 492 (1), article № 012028.
[4] Kulakov, D., Kulakov, B. Study of the dynamics of an electro-hydraulic servo drive physical model on FESTO learning system (2019) IOP Conference Series: Materials Science and Engineering, 492 (1), article № 012029.
[5] Sosnovskiy, N.G., Popov, D.N., Siukhin, M.V. Sensitivity of dynamic characteristics of electrohydraulic servo drive (2018) Proceedings — 2018 International Conference on Industrial Engineering, Applications and Manufacturing, ICIEAM 2018, article № 8728669.
[6] Popov, D.N., Sosnovskiy, N.G., Siukhin, M.V. Control of synergetic processes to ensure the asymptotic stability of hydraulic systems (2017) Herald of the Bauman Moscow State Technical University, Series Natural Sciences, (3), pp. 37–51.
[7] Mel'nikov E., Danilushkin I. Control system for the upper working gates of the shipping lock. Access mode: https://www.cta.ru/cms/f/454331.pdf (Date of access: 04.09.2019).
[8] Oleg, T. The experience of creating compact energy efficiency hydrostatic servo drive (2015) Proceedings of 2015 International Conference on Fluid Power and Mechatronics, FPM 2015, article № 7337187, pp. 603–609.
[9] Sobolev V. Achilles' heel of proportional hydraulics. Access mode: https://konstruktor.net/podrobnee-hidr/axillesova-pjata-proporcionalnoj-gidravliki.html (Date of access: 21.10.18).
[10] Turning accuracy. Access mode: http://gagar.ru/news/tochnost_tokarnoj_obrabotki/2017-05-09-1131. (Dateofaccess: 10.21.18).
[11] Kushnir N.A., Zyubin I.A., Development of a method for converting a discrete control valve into a proportional one using a stepper motor // Network publication "Hydraulics". — 2019. — Issue № 7. Access mode: http://hydrojournal.ru (Date of access: 2.07.2019).
[12] Kushnir N.A., Zyubin I.A., Russian Federation patent № 2686242. Digital control valve. 2019.04.24.
[13] Pavel, S. Electro-hydraulic drive with separate control of piston groups (2015) Proceedings of 2015 International Conference on Fluid Power and Mechatronics, FPM 2015, pp. 498–500.
[14] Kogler, H., Schöberl, M., Scheidl, R. Passivity-based control of a pulse-width mode operated digital hydraulic drive (2019) Proceedings of the Institution of Mechanical Engineers. Part I: Journal of Systems and Control Engineering, 233 (6), pp. 656–665.
[15] Rybarczyk, D. Investigation of electrohydraulic valve with the stepper motor (2018) AIP Conference Proceedings, 2029, article № 020068.
[16] Vanin, V.A., Kolodin, A.N., Rodina, A.A. Stepper hydraulic motor with pneumatic (jet) control system in machines with hydromechanical forming links (2019) Journal of Physics: Conference Series, 1278 (1), article № 012019.
[17] Ivanov G. M., Sveshnikov V. K., Sazanov I. I. Russian Federation patent №2505716 Digital control valve. 2014.01.27.