L. G. Kozlov, Cand. Sc. (Eng), Assist. Prof.; V. A. Kovalchuk; O. V. Piontkevich; M. P. Korinenko

INVESTIGATION OF STATIC AND DYNAMIC CHARACTERISTICS OF HYDRAULIC UNITS CONTROL SYSTEMS BASED ON PROPORTIONAL SOLENOIDS

The paper considers the problem of controlling hydraulic units by means of proportional solenoids. The results of experimental research on static and dynamic characteristics of proportional solenoids are presented. Recommendations, which could be used for designing hydraulic units controlled by proportional solenoids, are elaborated.

Keywords*: proportional solenoids, hydraulic unit control system, test unit.*

Problem statement. Hydraulic units with proportional electrohydraulic control have found wide application in many branches of industry and agriculture, particularly, in hydraulic drives of CNC machine tools, industrial robots, various technological equipment and mobile working machines. In the general case, control systems of such hydraulic units include: a control board, a system of data collection and analysis, control signal generator and a proportional electromechanical converter [1]. The most common control systems are those, where the functions of data collection and analysis as well as electric control signal formation are performed by programmable microprocessor devices (freely programmable controllers) and proportional solenoids are used as electromechanical converters.

As operation of hydraulic drives of mobile and technological machines in dynamic modes is characterized by frequent changes of operating and loading conditions, there is a necessity to develop control algorithms which adjust control signals in accordance with characteristics of both the hydraulic drive and its control system. Taking into account that design power of freely programmable controllers provides high data processing speed and linearity of signal conversion, investigation of static and dynamic characteristics of proportional solenoids is of critical importance in the development of control systems for hydraulic drives of mobile and technological machines [2, 3].

The use of proportional solenoids does not require high adjustment forces, provides simplicity of control and high output power but sets increased requirements to the quality of working fluid and involves technological difficulties of manufacture [4, 5]. Directional control valves are not sensitive to the working fluid quality, provide high leak tightness but have increased dimensions and lower accuracy. In [6] it is shown that flapper nozzle-based hydraulic equipment is characterized by relatively simple design, high power of the output signal and is less sensitive to the working fluid purity. However, its essential disadvantages include openness of the nozzle channel, which prevents from locking the controlled pressure channel and cavities connected with it, as well as changes of control pressure from maximal to minimal values.

Statement of the task. This work aims at the elaboration of recommendations on designing proportionally controlled hydraulic units and formation of control signals on the basis of experimental investigation of the entire control circuit and proportional solenoids in particular.

To achieve the goal, it is necessary to solve the following tasks:

- to design a test unit than includes the source of signals, microprocessor control device and proportional solenoid;
- to determine static characteristics of the control system;
- to determine dynamic characteristics of the control system.

Main results. Fig. 1 shows the design of pressure relief section of the directional control valve that includes a valve with proportional electromagnetic control. The section comprises body 1, directional spool 2, cutoff element 3 of the valve, valve seat 4 with a throttling channel 5, proportional solenoid 6 and springs 11, 12. As pressure in working lines of the directional control valve depends on the combination of the spring compression force and the force at the solenoid armature as well as on the adjustment of the stroke of cutoff element 3, quality of parameter regulation in hydraulic system, that includes this directional control valve, depends on static and dynamic characteristics of solenoid and also on the solenoid armature displacement setting.

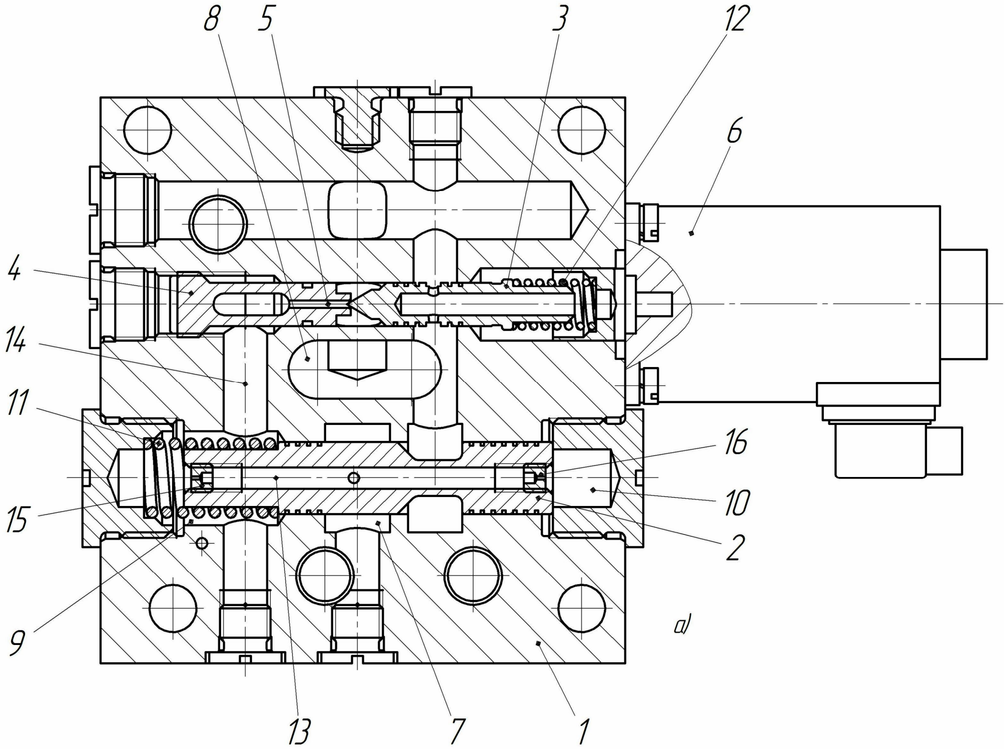


Fig. 1. Design of the valve with proportional solenoid control

For the research two proportional solenoid models were used: MFZ1-5.5YC, produced by SAL Company (China) and ZO(R)-A produced by ATOS Company (Italy). For studying static characteristics of solenoids test unit was developed. It includes power unit 1 that comprises voltmeter 2 and voltage regulator 3; solenoid 4 (to be investigated) that is rigidly fixed on a support column with movable table 7 and guide 6; electronic scales 8 and dial indicator (see Fig. 2).

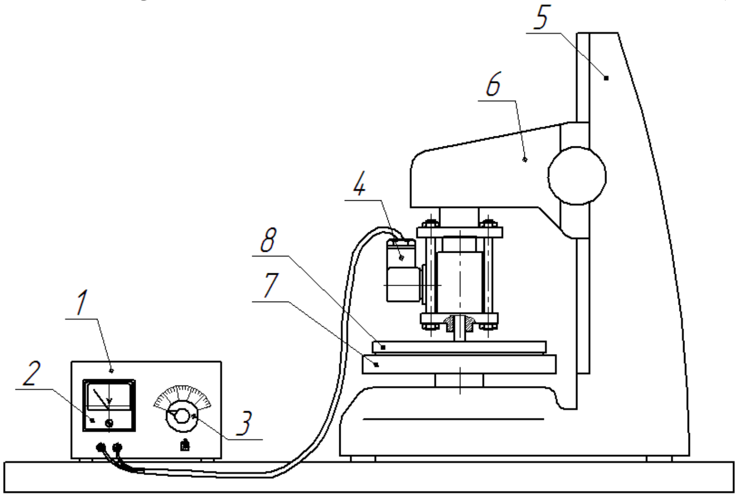


Fig. 2. Test unit for studying static characteristics of proportional solenoids

Wile studying static characteristics of solenoids, dependence of the created force on the armature displacement was built. Displacement of the support surface of the electronic scales was also registered in order to introduce correction of the solenoid armature shift relative to the extreme position. Investigations were performed for different voltage levels in the solenoid wire. Fig. 3 presents the results of studying static characteristics of proportional solenoids for different values of voltage in the wires.

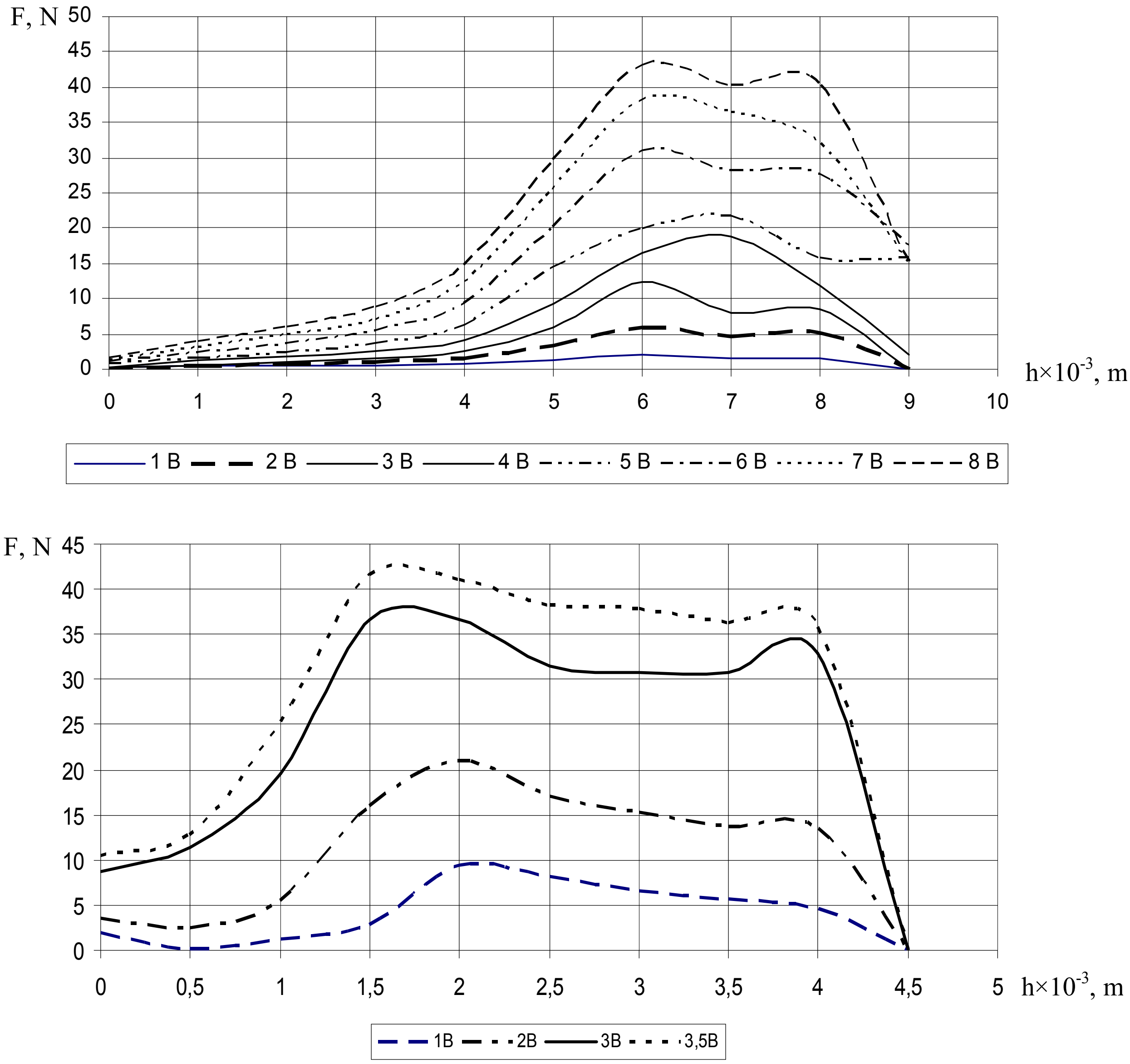


Fig. 3. Static characteristics of proportional solenoids:
a) MFZ1-5.5YC and b)ZO(R)-A for different values of voltage in the control wire.

By the research results it was determined that for solenoid MFZ1-5.5YC power stroke is the range of 6-8 mm of the armature displacement and for solenoid ZO(R)-A – 2.5 – 4 mm. Besides, for small voltages a more considerable drift of characteristics with deviation of the force in the range of 5 – 12% for solenoid MFZ1-5.5YC and 3-7% – for solenoid ZO(R)-A is characteristic. On the whole, the research has shown that static characteristic of solenoid ZO(R)-A has a more distinct power stroke portion and force variations at this portion do not exceed 7% and are reduced with voltage growth. Solenoid MFZ1-5.5YC has quite a large zone (from 0 to 4 mm of the displacement) where there is a minimal growth of the force, which could be due to special design features of the solenoid coil.

In order to study dynamic characteristics, it is important to determine the influence of all the control system components, including signal normalizers and converters, on the shape and value of the output electric signal. While studying the character of transient process, the following parameters were registered: electric parameters of the input signal created by low-frequency signal generator Г3-112/1, of the output signal of the microprocessor device and of the voltage in the coil wire of the proportional solenoid.

Fig. 4. presents block-diagram of the test unit for determining dynamic characteristics of the proportional solenoids.

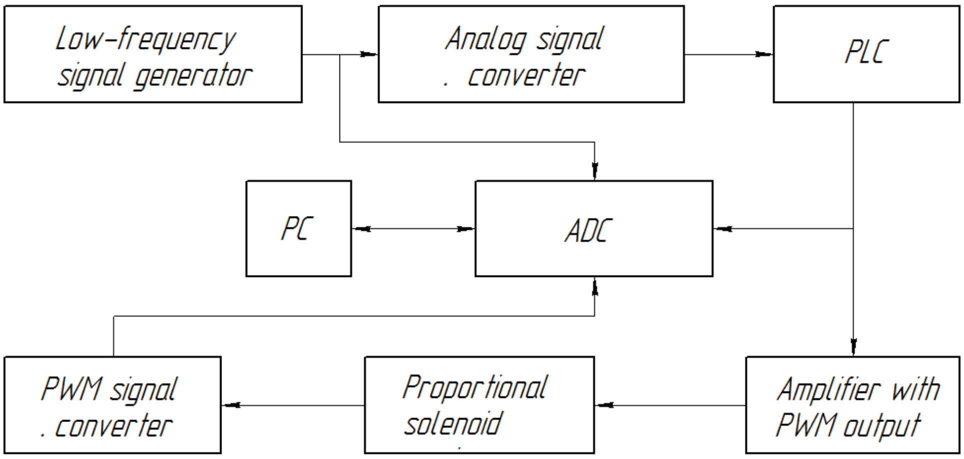
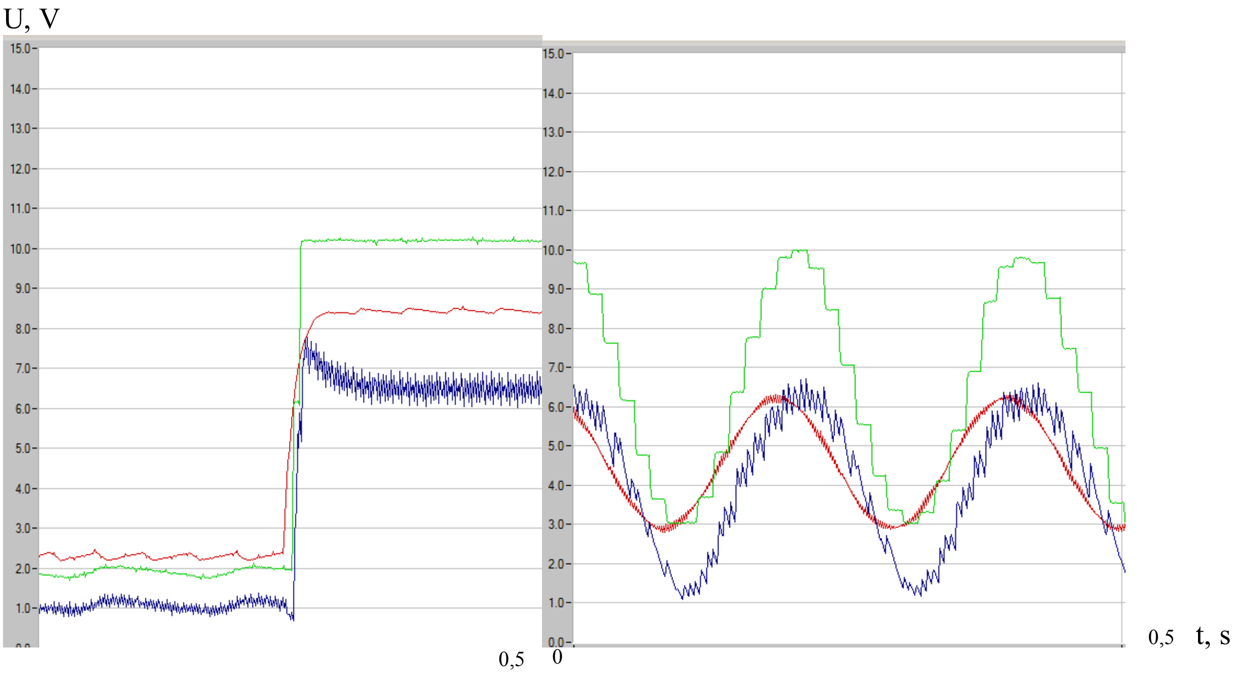


Fig. 4. Block-diagram of the test unit for determining dynamic characteristics of proportional solenoids.

Fig. 5. presents the view of transient process in the control system, obtained during investigations, when step and harmonic signals were supplied to the control system input.



0 Fig. 5. The character of transient process when different signals were supplied to the control system input: a) step signal; b) harmonic sinusoidal signal.
1) input signal; 2) signal at the output of the microprocessor device; 3) voltage level variations in the coil of the proportional solenoid.

The obtained transient process has aperiodic, damped character with overshooting in accordance with the value of voltage in the solenoid spool σ = 15% and regulation time t_p = 0,08 s. When a smoothly variable signal (e.g. according to a sinusoidal law) is supplied to the control system input, overshoot value reduces to 3% and regulation time t_p = 0,05 s.

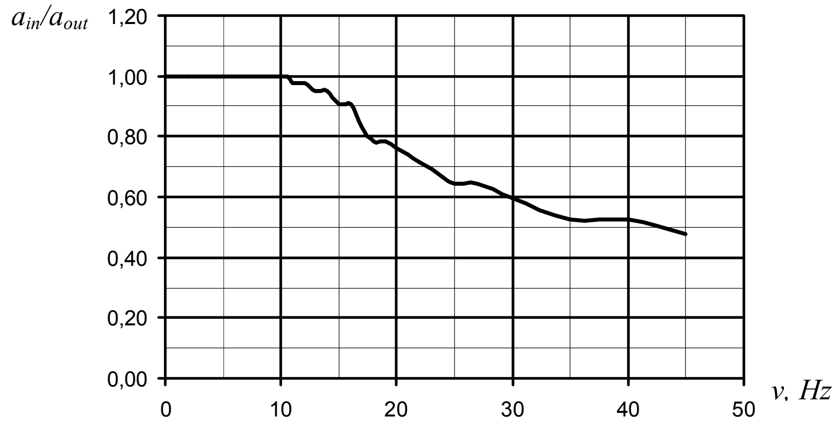


Fig. 6. Amplitude-frequency characteristic of the control system, based on solenoids with proportionally-controlled working parameters.

In order to determine passband in the control system, its amplitude-frequency characteristic was built. For this, a sinusoidal signal in the frequency range from 0.5 to 45 Hz was supplied to the control system input. Fig. 6 presents the dependence of the ratio of the input and output signal amplitudes on the frequency. Steady value of the ratio of amplitudes is maintained up to the frequency of 10 Hz and at the frequency of 25 Hz output reduces by 30%. Therefore, application of such control system at the frequency above 25 Hz is not permissible.

Conlusions

1. In designing hydraulic units it is necessary to be guided by the regions of working strokes of proportional solenoids, determined experimentally: for solenoid MFZ1-5.5YC – 6 – 8 mm and for solenoid ZO(R)-A 2.5-4 mm;

2. Control system, based on free-programmable controllers and proportional solenoids MFZ1-5.5YC or ZO(R)-A, can be used at frequencies not exceeding 25 Hz;

3. Astatism of the measuring system is, on the whole, 8% for solenoid ZO(R)-A and 12% for solenoid MFZ1-5.5YC.

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Kozlov Leonid – Cand. Sc. (Eng), Prof. with the Department of Machine Building Technology and Automation, osna2030@gmail.com;

Kovalchuk Vadim – Engineer.

Piontkevich Oleg – Student.

Korinenko Mykola – Student.

Vinnytsia National Technical University.