

Structural model of control system for hydraulic stepper motor complex

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Abstract. The article considers the problem of developing a structural model of the control system for a hydraulic stepper drive complex. A comparative analysis of stepper drives and assessment of the applicability of HSM for solving problems, requiring accurate displacement in space with subsequent positioning of the object, are carried out. The presented structural model of the automated control system of the multi-spindle complex of hydraulic stepper drives reflects the main components of the system, as well as the process of its control based on the control signals transfer to the solenoid valves by the controller. The models and methods described in the article can be used to formalize the control process in technical systems based on the application hydraulic stepper drives and allow switching from mechanical control to automated control.

1. Introduction

At the moment, stepper motors (SM) are used in various industries and, above all, in the design of CNC machines. In this case, the electric SM are the most common, however, this type of engine has significant drawbacks, which do not allow applying them in complexes that require synchronous rotation of multiple spindles.

The most effective method is the use of hydraulic SM (HSM) to solve such problems. However, nowadays the control of such motors is carried out mechanically, that does not allow preceding the automated control on them. In this article, we consider a structural model of the control system for the HSM complex, which will realize the operational control of HSM, for example, when designing omnidirectional treadmills in simulator complexes using virtual or augmented reality technologies.

2. Stepper motors analysis

The problems on the selection of working motors performing these functions [1] appear at manufacturing mechanisms requiring synchronous rotation of output elements with their precise positioning.

It is possible to use stepper motors or servomotors [2-4] to solve this problem.

In most cases this task can be mastered by the electric SM (ESM). They have high reliability, because there are no wearing parts in their design [5]. The working resource of the engine depends only on the resource of the bearings used in it. However, when they work, the effect of losing steps occurs. This effect is established in some uncontrolled displacement of the trajectory of movement of the output link from the necessary trajectory, which emerges when the drive doesn't meet acceptable parameters, if it is not properly controlled, or has "problems" with mechanics. Also at high speeds, the torque falls that in turn leads to errors in positioning the final elements of the mechanism. The



expensive rare earth magnets are applied in them, as well as the rotor and stator are manufactured with precision accuracy, and therefore, the stepper drives have a higher cost compared to general industrial electric motors. However, the discreteness of the step creates significant vibrations, which in a number of cases can lead to a decrease in the torque and the excitation of mechanical resonances in the system, as well as the possibility of “slippage” of the rotor, that occurs when the load on the shaft is exceeded or when the control program is incorrectly adjusted. The level of vibration can be reduced by using the mode of division the step or with increasing the number of phases; the motor’s power is often increased to avoid slippage of the rotor. Their low maintainability should be noted as well.

The effect of steps loss of for servomotors is completely absent. Because each servomotor has a position sensor (encoder), which constantly monitors the position of the motor’s rotor and, if necessary, issues the position correction commands, on the basis of which the control electronics, analyzed the data from the encoder, generates the necessary control signals for the motor. This mechanism is called feedback. In machines operating on the basis of servo drives, when the moving parts collide with an obstacle, the control electronics determine that there was an increase in the load and it increases the level of current supplied to the motor for compensation. With a full forced stop, the servomotor receives the maximum current, so if the control system does not monitor this situation, then the motor may be burned. Hence, a number of shortcomings in the use of servomotors in the manufacture of mechanisms requiring synchronous rotation of the output elements with their precise positioning are disclosed: a sufficiently high price, a complex control system, low maintainability, a careful attitude to the motor is required.

The use of a hydraulic drive represents one of the possible practical ways to improve the accuracy of positioning in the space of the system’s output links when it is necessary to accurately synchronize the rotation of all power elements, and HSM with mechanical step reduction is applied to improve the accuracy of positioning in the space of the output link.

A hydraulic stepper drive is a new class of three-dimensional hydraulic drives. Their functional properties include the sustainable operation of relay and impulse control signals with high accuracy at almost any encountered load [6].

HSM is a structure of an axial-plunger motor of rotary motion. It differs structurally from the conventional axial-plunger machine with the absence of internal distribution of the working fluid, and the rotor is used instead of the swashplate with a row of cams on the frontal surface [7, 8]. Their application instead of one swashplate allows increasing the torque on the output shaft of the HSM by changing the angle of ascent of the rotor cams profile under otherwise equal conditions. Each of these cams individually acts as an inclined swashplate of a conventional plunger machine.

HSM structurally consists of a frame into which a drive shaft is mounted on the rolling bearings, where a rotor with cams interacting with the pushers is fixed. The rotor in the sweep represents a rack-type gear, the pushers are displaced relative to each other by one third of the step of the gear. The pushers move freely in the stator bores [9]. The stator is pressed against the frame by a lid, where the holes for the fittings of the pipelines are located. Under the action of the hydraulic impulse the pusher moves, interacting with the rotor cam bevel, turning the latter to a certain angle. The feature of the motor is displayed in the absence of movement; the rotor is rigidly fixed by pushers in the space between the cams, which ensures self-braking of the system. The direction of rotation of the motor in one direction or the other is determined by the selected order of the hydraulic impulses.

The application of hydraulic stepper motors is explained by the main advantages of the hydraulic drive, the main of which are [10, 11]:

- a. high energy intensity; low weight and volume per unit of power, therefore, in comparison with the electric drive it has a more favorable weight characteristic. So the weight of hydraulic systems is approximately 20-30% less than similar electrical installations;
- b. small inertia of hydraulic drives in comparison with others, similar in purpose and power;
- c. ease of stepless speed regulation and a wide range of their regulation;
- d. ability to perceive significant dynamic loads and ease of protection against overloads;
- e. insensitivity to overload due to limitation of operating pressure;

- f. simplicity of the construction and possibility of obtaining the most convenient layout;
- g. possibility to ensure high speed of executive parts due to low inertia;
- h. high wear resistance of hydraulic drive elements because of good lubrication conditions, and liquids with high lubricating properties are used as a working medium.

The listed advantages allow concluding that the use of hydraulic stepper drives in solving a number of problems is justified. An example of such task may be the development of an omnidirectional treadmill used for training in virtual simulators. However, for the implementation of such track, a set of synchronized drives is required.

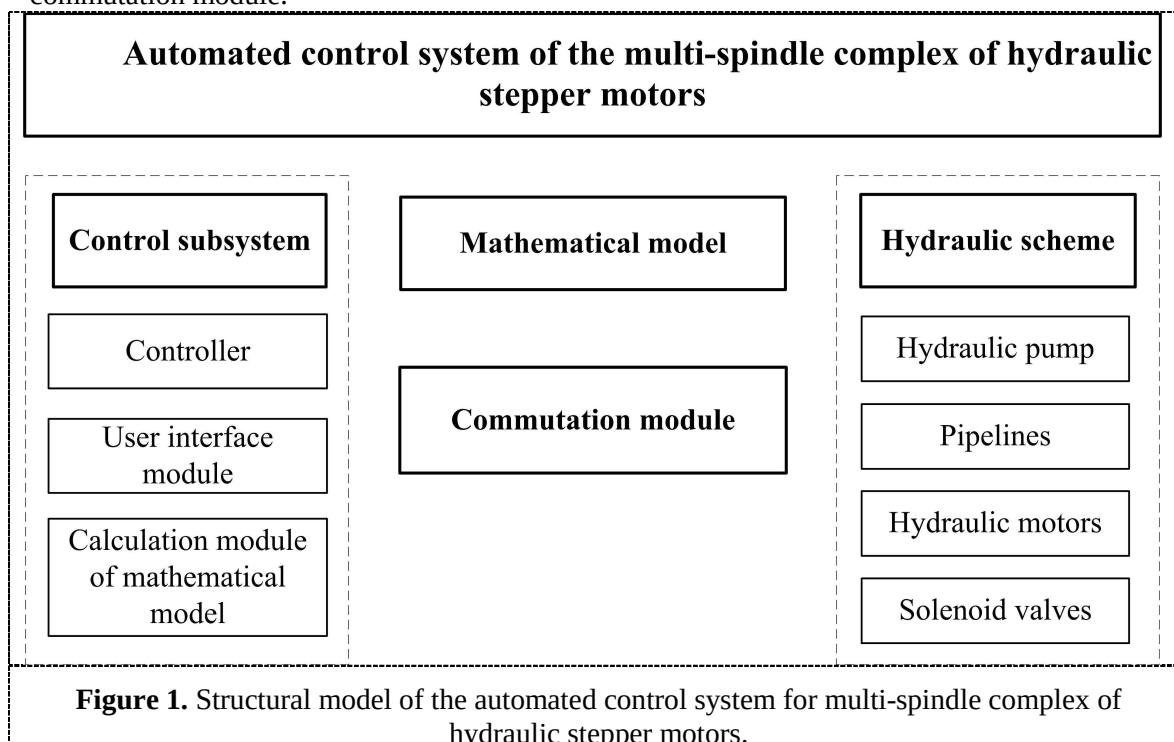
The analysis of the literature showed that no research was conducted in this area, and electronic control systems that allow programming a hydraulic motors complex were not developed at all. This subject is relevant and important from the scientific and practical point of view considering the application of various hardware and software, it is possible to transfer programs to a hydraulic motors complex in the form of a sequence of signals and thus carry out any actions. However, the implementation of both the hydraulic motor control system and the implementation of the hydraulic drive scheme itself are impossible without a preliminary simulation and system analysis of the overall structure of the developed system.

3. A structural model of the automated control system for multi-spindle complex of hydraulic stepper motors

The implementation of the multi-spindle complex of the hydraulic stepper motor control system requires the development of a structural model of the general system, which includes the main components, analysis of the information flows and formalizes the processes of interaction between the individual components.

The automated control system of the multi-spindle complex of hydraulic stepper motors consists of three main components (fig. 1) [10]:

- hydraulic scheme,
 - control subsystem,
 - mathematical model of system's functioning;
- commutation module.



Let's consider each of the components.

The hydraulic scheme is a combination of a source of working fluid 1 connected by a pipeline to the working chambers of the HSM 4 through high-speed solenoid valves 2 which operation depends on the control subsystem 3. Varying the connection scheme, it is possible to obtain both the synchronous operation scheme of the HSM (fig. 2a), and the scheme with individual control of each engine (fig. 2b) [11].

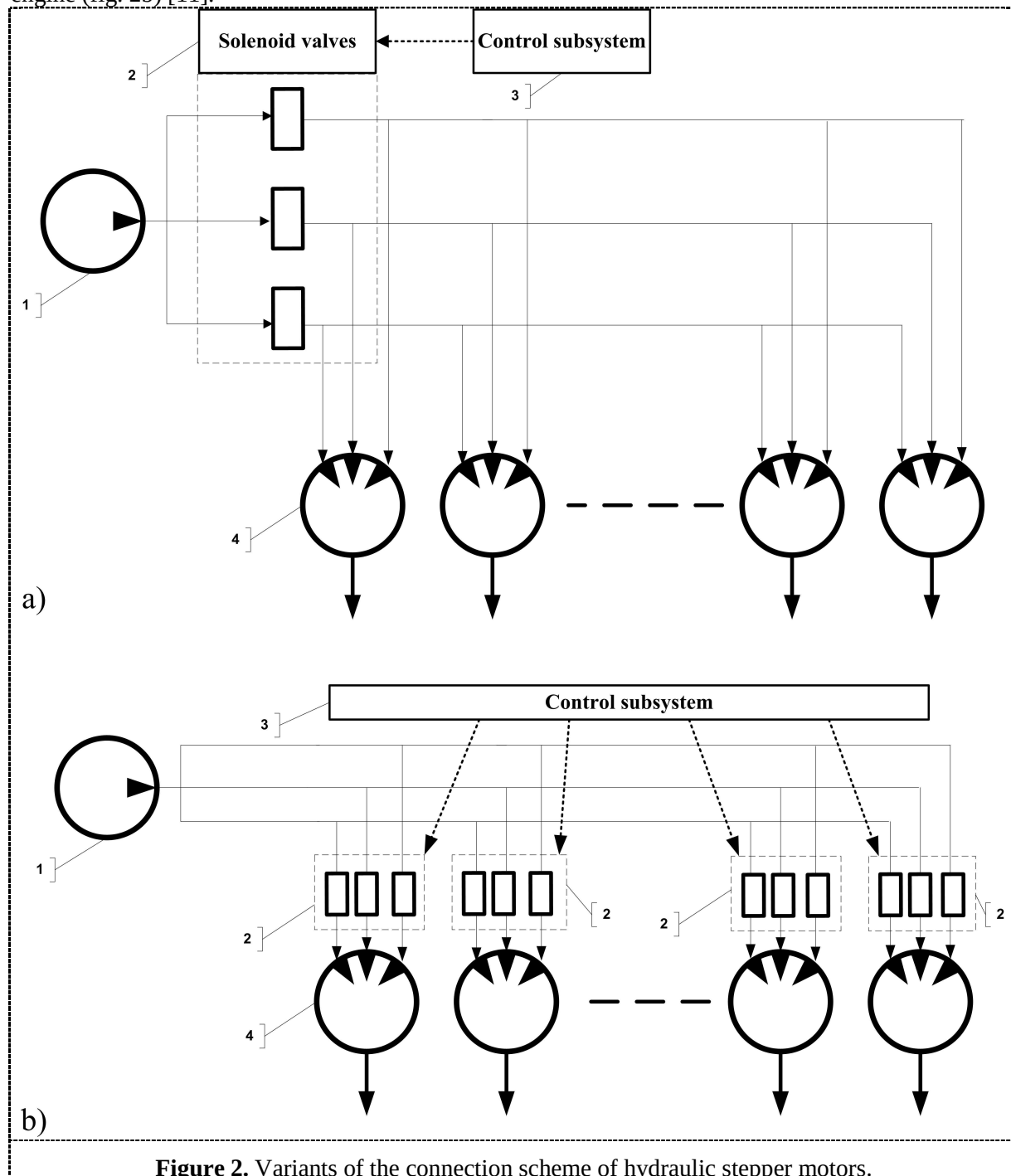


Figure 2. Variants of the connection scheme of hydraulic stepper motors.

The synchronous scheme differs from the individual one to the extent that it controls the hydraulic motors by means of only 3 solenoid valves, the hydraulic pressure from which is simultaneously

distributed to all the motors. With individual control each motor has its own valve system 2 connected to the control subsystem that allows each motor to be controlled in the required mode.

At the basis of the **control subsystem** is the hardware link “controller-relay-valve”. The control signals from the controller are applied to the relay, which leads to the opening or closing of the solenoid valve. In addition to hardware, the subsystem includes a number of software and hardware modules: a user interface module and a calculation module of mathematical model.

The user interface module includes software that implements the interaction of the human operator with the hydraulic scheme through a human-oriented interface. This module can also be designed as a universal hydraulic scheme control environment by sending a program in the form of a series of commands, which are after converted into a sequence of signals opening or closing the solenoid valves.

The module for calculating the mathematical model makes it possible to form, based on the regularity of the model of hydraulic motors, the sequence of commands for the control subsystem, which can then be transferred to the controller.

The switching module provides communication between the control subsystem and the hydraulic scheme, transmitting the signals received from the controller to the solenoid valves.

To connect the hardware (hydraulic circuit, controllers, valves, etc.) and software (modules of the control subsystem), it is necessary to develop a mathematical model for the functioning of the automated control system for a multi-spindle complex of hydraulic stepper motors, which will be presented in a set-theoretical form that will permit to formalize the structure of the system, as well as the processes of interaction of its main components.

Then the mathematical model of M system functioning is represented in the following form:

$$M(HS, S, P) = R, \quad (1)$$

$$HS = (HP, PL, H, V), \quad (2)$$

where HS – hydraulic scheme;

$S = \{sm_i\}$ – control subsystem consisting of modules sm_i ;

$P = \{p_m\}$ – program in the form of a sequence of signals p_m from the controller C ;

R – result of the system operation, which, corresponds to the required $R = R^*$; if the system functions correctly;

HP – hydraulic pump;

$PL = \{pl_j\}$ – set of pipelines;

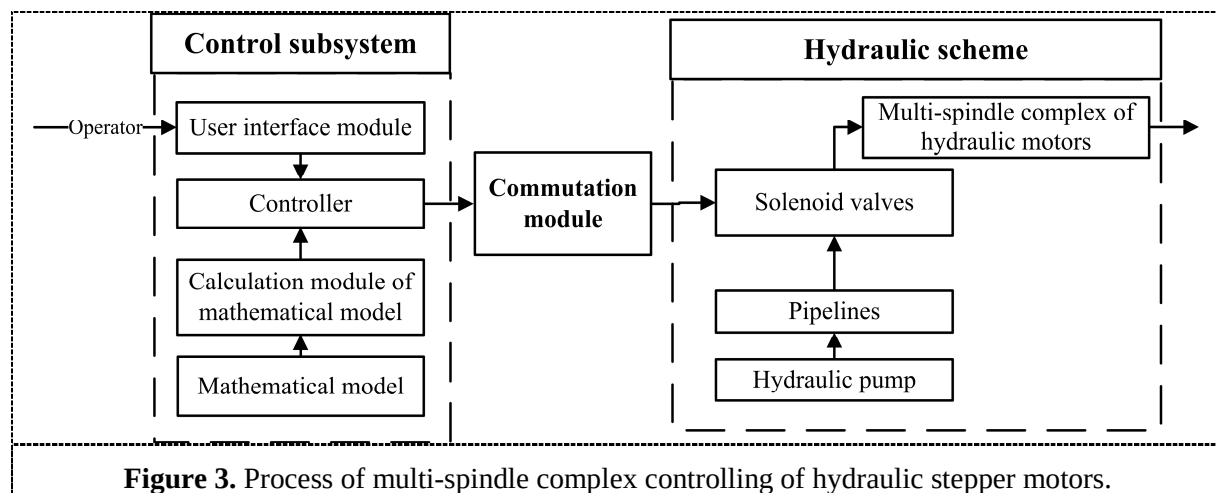
$H = \{h_i\}$ – set of HSM;

$V = \{v_l\}$ – set of valves.

The control subsystem transmits control signals through the “controller-relay-valve” connection, which leads to the opening or closing of the valve. In a formalized form this can be represented as follows:

$$S(p_m): V \rightarrow \{0,1\}. \quad (3)$$

Then, the process of controlling the multi-spindle complex of hydraulic stepper motors can be represented by the following scheme (fig. 3).



Using the presented structural model, it is possible to design and develop a system for automated control of a multi-spindle complex of hydraulic stepper motors, as well as its control by control signals supply to solenoid valves. Such structure will allow synchronous control of the HSM, which is especially important for equipment that requires an accurate movement in space with subsequent positioning of the object, for example, when developing an omnidirectional treadmill.

4. Conclusion

The article presents a comparative analysis of stepper motors, which resulted in a conclusion about the applicability of HSM for solving problems requiring precise movement in space with subsequent positioning of the object.

A structural model of the automated control system for the multi-spindle complex of stepper motors is presented, which reflects the main components of the system, as well as the process of its control based on the control signal transfer to the solenoid valves by the controller.

The approach to the formalization of functioning process of the automated control system for multi-spindle complex of hydraulic stepper motors using the methods of set theory is considered, the scheme of the multi-spindle complex control process is constructed.

The models and methods described in this article will allow us to formalize the control process in technical systems based on the use of hydraulic stepper drives, which will allow switching from mechanical control to automated control that can find its application in the development of omnidirectional racetracks for training complexes.

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