Stepper hydraulic motor with pneumatic (jet) control system in machines with hydromechanical forming links

V A Vanin¹, A N Kolodin¹ and A A Rodina¹

¹Tambov State Technical University, 106 Sovetskaya Street, Tambov 392000, Russian Federation

¹E-mail: ant.rodina1209@yandex.ru

Abstract. The practical feasibility of using hydraulic links based on a stepper hydraulic drive with a jet control system in the internal circuits of machine tools has been considered. The application of hydraulic links based on stepper hydraulic motor in the internal circuits of the machines is constrained by the lack of fast-retrofitting control systems, functionally similar to switches, meeting the requirements of high accuracy (low step cost), high reliability requirements (no impulse skip).

1. Introduction

One of the ways to improve the accuracy of machine tools while increasing their operational reliability is to reduce the length of kinematic chains, due to the use of drives that allow the executive motor to be directly connected to the load (billet and tool), eliminating intermediate mechanical gearboxes, gear shift transmission, gear reduction boxes, feed boxes [1, 2].

Most clearly, this need appears in gear-manufacturing machines, having in their content the complex branched multi-link kinematic internal chains of considerable length, where it is necessary to provide a rigid kinematic connection to create an exact interconnected formative movement between the billet and the tool.

One of the possible solutions to reduce the length of the kinematic chain in order to improve the accuracy, rigidity of the machine, reduce metal consumption and machine weight, can be the application of hydraulic connections made in the form of a hydraulic stepper drive. This can be explained due to the well-known advantages of the hydraulic motor: small dimensions and weight with a high specific force strength, which ensures low inertia of moving parts, high speed and accuracy of reproduction of interrelated movements.

Hydraulic stepping motors are used as executive power bodies in hydraulic connections; these motors convert the sequence of hydraulic control pulses into discrete angular or linear displacements, while the rotational speed and the total angle of rotation of the output shaft of the stepping hydraulic motor are proportional to the frequency and number of applied control pulses; in the absence of output signals, the link is held in a fixed position [2].

The use of discrete devices allows you to significantly simplify the control system, to obtain sufficient accuracy and speed when the control system is open due to a one-to-one correspondence between the number and frequency of control pulses, the number and frequency of discrete movements (angular or linear) at the output of the actuators.

Using the properties of frequency regulation of speeds of executive power stepper hydraulic motors, it is possible to replace the mechanical kinematic connection between the billet and the tool in...
a gear manufacturing machine of the synchronous communication hydraulic system, which ensures high accuracy of the agreed angular movements of the billet and the tool [3, 4].

2. Main part
The application of hydraulic links based on stepper hydraulic motor in the internal circuits of the machines is constrained by the lack of fast-retrofitting control systems, functionally similar to switches, meeting the requirements of high accuracy (low step cost), high reliability requirements (no impulse skip).

One of the possible ways to solve these problems can be the use of jet technology.

The control system (CS) of hydraulic stepper motors (HSM), located in the hydraulic rollback chain (division), for a drive of the tool billet is implemented on the element base of Volga system, provides adjustment of the gear ratio and the possibility of cutting gear wheels with an arbitrarily specified number of teeth [5-6].

The structural scheme of CS is presented in figure 1.

![Figure 1. Structural scheme of CS dividing hydraulic chain.](image)

System operation parameters, i.e. information about the gear ratio of the dividing chain, step, direction of rotation of the output shafts of HSM is set on the control panel 1. Information from the control panel enters the control device 2, which ensures generation in a certain sequence of control pulses of stepping hydraulic motors of execution devices 4 located in the drive units of the billet and shape cutter. Block of pneumohydraulic discrete transducers-amplifiers (PDTA) 3 serves to coordinate HSM of jet CS. The pulses coming from the jet CS exit switch the membrane actuator of the first cascade, which controls the hydro relay of the second cascade, which converts the continuous flow of working fluid into a sequence of hydraulic pulses coming into the plunger chambers of the main hydraulic unit and causing their output shafts to turn at a certain angle.

When building such a system, one should take into account the features of controlling multi-step hydraulic motors. The operation of a stepper hydraulic motor depends on the number and sequence of hydraulic impulses in the power working chambers of the stepping hydraulic motor, and each control pulse corresponds to a certain angle of rotation of the output shaft of the HSM. The speed of rotation
and the total angle of rotation of the output shaft are proportional to the frequency and number of control pulses, respectively.

Connection diagram through PDTA block of stepper hydraulic motor is shown in figure 2.

![Connection diagram of stepper hydraulic motor.](image)

**Figure 2.** Connection diagram of stepper hydraulic motor.

The sequence of supplying control signals is presented in the table of a stepper motor functioning (Table 1).

**Table 1.** Stepper motor functioning.

| Step | Numbers of plunger cameras | Direct move | | | Reverse move |
|------|-----------------------------|-------------|-------------|-------------|
| | | I | II | III | I | II | III |
| 2° | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 1 | 0 | 1 | 1 | 0 |
| | 3 | 0 | 0 | 1 | 0 | 1 | 0 |
| 4° | 4 | 1 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 1 | 0 | 1 | 1 | 0 |
| | 6 | 0 | 0 | 1 | 0 | 1 | 0 |
| 6° | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| | 2 | 0 | 1 | 0 | 0 | 1 | 0 |
| | 3 | 0 | 0 | 1 | 1 | 0 | 0 |
| | 4 | 1 | 0 | 0 | 0 | 0 | 1 |
| | 5 | 0 | 1 | 0 | 0 | 1 | 0 |
| | 6 | 0 | 0 | 1 | 1 | 0 | 0 |

Note: 1. I, II, III - numbers of cycles.
2. 1 - fluid pressure is supplied to the plunger chamber; 0 - plunger chamber communicates with the drain.

The main unit of the control system is the control device 2, the structural diagram of which is shown in figure 3.
Figure 3. Structural diagram of control device.

Since the control system of the hydraulic link of the dividing chain of a gear-manufacturing machine is open-circuited, the beat pulses are generated by the beat generator (BG) 1, which sets the rate of operation of the entire device and is the standard of time. Next, the signals arrive at the input of frequency divider 2, which, depending on the required gear ratio (ratios of the rotational speeds of the output shafts of the high-pressure heads HSM), transmits pulses with certain numbers. The circuit of the frequency divider is shown in figure 4.

The frequency divider is an indicator with a variable division factor. It is built from a four-digit binary indicator, the outputs of which are connected to a coincidence circuit assembled on elements of unevenness or, which is the same for the function of two variables, module 2 sum. A trigger with a counting input is used as the base cell of the indicator. In the coincidence circuit, the required frequency of the output signals in binary code \( \{a_1, a_2, a_3, a_4\} \) is set. The frequency of the output signals from the divider will be determined by the following formula:

\[
f_{\text{out}} = \frac{f_{\text{bf}}}{(a_1 2^{n-1} + a_2 2^{n-2} + \ldots + a_n 2^{n-n})}
\]  

where \( f_{\text{bf}} \) - input beat frequency; \( n \) is the number of digits, in this case \( n = 4 \).

Figure 4. Frequency divider  
a) symbol; b) circuit
The pulses from the output of the frequency divider are fed to the input of a command-setting device 3, built on the principle of a reversing circulating device and consisting of an indicator with a conversion factor 3, the output of which is set by the decoder to three outputs (by the number of control channels of the stepper motor), which implements the appearance of a single signal on each of the outputs, as well as schemes for reversing and changing the step of the engines. A command-setting device (figure 5) provides the distribution of pulses from the output of the frequency divider in a specific sequence through the control channels for stepping hydraulic motors, as well as controlling the step of the motors and the direction of their shafts rotation.

![Figure 5. Circuit of command set device.](image)

The main element of the command set device is an indicator with a conversion factor 3, the circuit of which is shown in figure 6.

![Figure 6. Indicator a) symbol; b) circuit diagram.](image)

The indicator with counting ratio $K=3$ is built on the basis of a binary two-digit counter with $K=4$, which excludes one steady state by introducing a reset circuit.

The signals from the indicator outputs are fed to the input of a triple-charged decoder. The decoder, depending on the combination of input signals, ensures the alternate appearance of a high-level signal at its outputs. The decoder circuit is based on the following equations:

$$Y_1 = \overline{Q}_1 \cdot \overline{Q}_2$$
$$Y_2 = \overline{Q}_1 \cdot \overline{Q}_2$$
$$Y_3 = \overline{Q}_1 \cdot \overline{Q}_2$$
where $Q_1$, $Q_2$ – signals from the corresponding indicator bits.

The decoder is constructed according to a linear scheme, i.e. each of equations (1) is implemented by a separate logical element, its schematic diagram is shown in figure 7.

Another node of the command-setting device is the reverse unit, which is necessary to change the direction of rotation of the output shafts of HSM. The need for reverse occurs when processing some types of gears on gear-manufacturing machines (internal and external gearing). Input signals for the reverse block are a sequence of pulses from the output of the decoder $Y_1, Y_2, Y_3$. Reversing the shafts of stepper motors is carried out by changing the direction of the “overrun” of control signals. The reverse block functions based on the following logical dependencies:

$$ X_1 = Y_1 \overline{E} \lor Y_3 \; E \quad X_2 = Y \quad X_3 = Y_3 \overline{E} \lor Y_1 \; E $$

where $E$ - reverse start signal.

If $E=0$, then the reverse block repeats the input signals at its outputs, and if $E = 1$, then the signals at the first and third output take opposite values. The block diagram of the reverse is shown in figure 8. The block diagram of the step correction is shown in figure 9.

Hydraulic stepping motors, used in hydraulic internal circuits as power organs, can be made multi-step to expand the area of possible applications [7-8].

The hydraulic scheme of a stepper hydraulic motor provides the angular displacement of the rotor in increments of $2^\circ, 4^\circ, 6^\circ$, depending on the sequence in which their plunger groups are connected to the pressure lines.

The step control of hydraulic stepper motors is performed using a step correction unit. This block has three information inputs, which receive signals from the output of the reverse block, two control inputs $x_1$ and $x_2$ and six outputs. Depending on the combination of the code on $x_1$ and $x_2$ the signals from the input of the step correction block will be transmitted either to the first three outputs, or to the second three outputs, or to both groups of outputs simultaneously. The step correction block operates on the basis of the following logical equations:

$$ Y_1 = Y_1 x_1 \quad Y_1 = Y_1 x_2 
Y_2 = Y_2 x_1 \quad Y_2 = Y_2 x_2 $$

**Figure 7. Decoder**

a) circuit diagram; b) symbol.
\[ Y_3 = Y_3 x_1 \quad Y_4 = Y_3 x_2 \]

**Figure 8.** Reverse block

a) circuit; b) symbol.

**Figure 9.** Step correction block

a) schematic diagram; b) symbol.

The work of the jet control system is carried out under the action of a sequence of beat pulses generated by the driving oscillator. The beat pulse generator circuit is shown in figure 10. The generator is built on the element OR-NOT-OR type CT41, covered by feedback. The amplifier CT46 is introduced into the feedback circuit for stable operation of the generator at low frequencies (up to 8 Hz). RS-trigger is used, which is a trigger link, to start and stop the generator, and with it the entire jet control system [9-13]
A schematic diagram of a control system for stepper hydraulic motors of a hydraulic chain for rolling a gear-shaping machine is shown in figure 11.

Figure 11. Schematic diagram of control system by hydraulic link of gear manufacturing machine dividing.

Conclusions
The practical feasibility of using hydraulic links based on a stepper hydraulic drive with a jet control system in the internal circuits of machine tools consists of the following:
- the length of the kinematic chains is reduced by a possible minimum of the number of intermediate links constituting the internal kinematic chain, which greatly simplifies the kinematics of the machine;
- the manufacturability of the machine design is improved, providing a more rational layout with a complex spatial arrangement of the working elements of the machine;
- the metal consumption and weight of the machine decreases;
- the jet control system of stepper motors allows the regulation of the gear ratio of the rolling chains (division) of gear-manufacturing machines for the processing of products with an arbitrarily specified number of teeth.

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