

Kinematic Parameters Of Rotary Transmission With Hydraulic Cylinders

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Abstract. The issue of designing drives, which provide low frequency (max. 1 rotation per minute) rotation with a big moment (min 1 MN m) of large technical bodies utilized in restricted spaces, is a complex and contradictory one. The drives of geokhod propeller, rotor actuators of tunneling machines with overload protection, as well as actuators of other machinery meeting aforementioned requirements are examples of such machines. The paper considers mathematical model developed by the authors which determines the relation of design factors of transmission tooled with hydraulic cylinders to kinematic parameters of output element movement. The paper also provides description of methods to determine pumping unit efficiency for rotary transmission tooled with hydraulic cylinders.

1 Introduction

Conventional drives with mechanic transmission and electric or hydraulic motors are difficult to utilize because of insufficient mass-overall parameters [1-9]. It is also a problem to use rather perspective wave gears with interposing rolling elements because of their technical complexity and technological imperfection [10,11]. An alternative is suggested: a swinging mechanism tooled with hydraulic cylinders placed on chord of a circle and linear – rotary motion converter designed as a free-wheel clutch mechanism [12–14]. As all hydraulic cylinders are cyclic reciprocating hydraulic motors, the continuity of output element rotation is provided with out of phase operating hydraulic cylinders in most mechanisms, that is, one half of cylinders makes a power stroke and the other one – an idle stroke [15,16]. Mechanisms with more hydraulic cylinders making a power stroke than an idle stroke are considered to be more power efficient. For this purpose hydraulic cylinders are to be placed in different phases of extension (Fig. 1, 2).

The authors have already considered issues focused on determination of energy-power parameters of this type of transmissions. We have suggested a mathematical model to calculate a turning moment made by transmission according to accepted dimensions of geokhod, necessary clearance of internal space, and conditions of mine working [2, 3].

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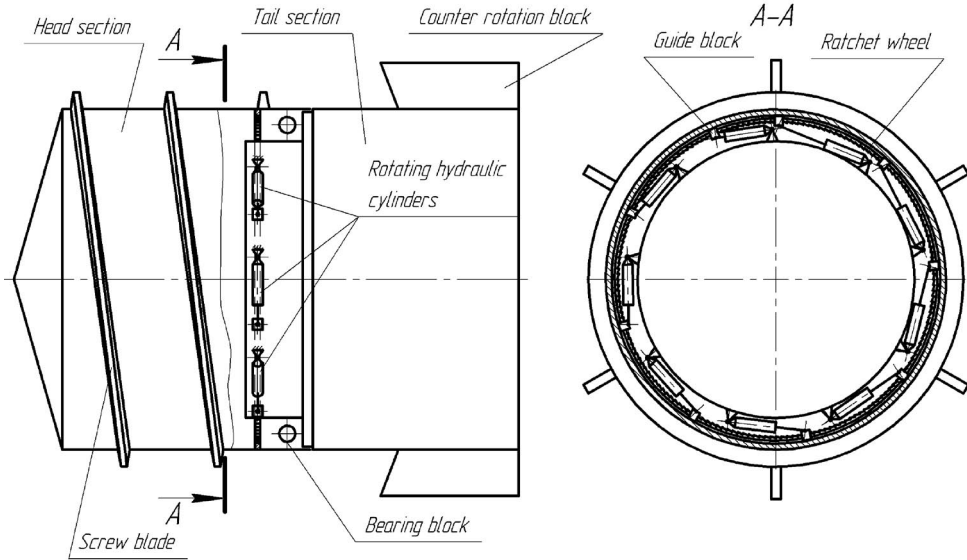


Fig. 1. Outlined design of constant bottom-supply geokhod transmission tooled with two groups of hydraulic cylinders in different extension phases in one plane.

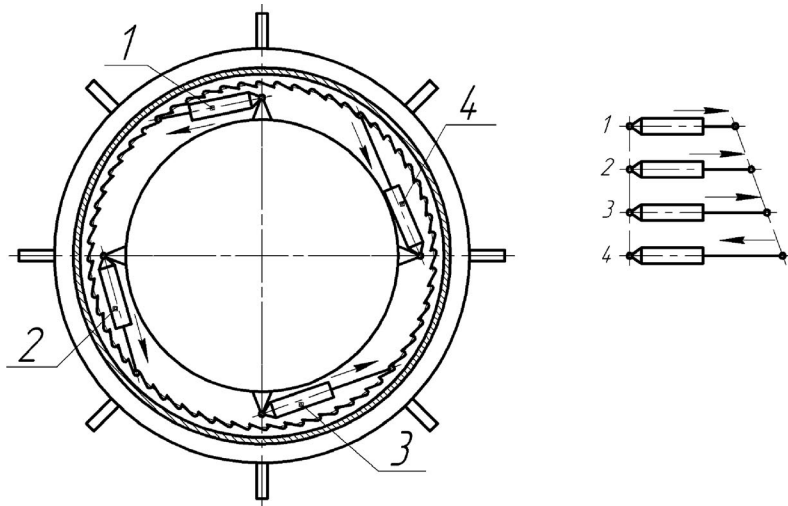


Fig. 2. Explanatory design of operating transmission with hydraulic cylinders in different phases

It is stated in paper that the moment made by transmission tooled with hydraulic cylinders will change periodically because of alternating lever of force exertion by hydraulic cylinders. We have also studied the effect of geometrical parameters of transmission and the number of hydraulic cylinders on the value of moment inequality. Another major influence on the geometric parameters of the transmission will have the technological features of manufacture geokhod housing [17–19].

2 The mathematical model

This paper is suggested to focus on determining kinematic parameters of rotary transmission tooled with hydraulic cylinders, in particular – on angular rate and output

element angular rotation (head section with propeller) specific for a stroke of hydraulic cylinder rod, as well as on relation of these parameters to design factors of transmission and geometrical parameters of geokhod.

If a hydraulic cylinder rod is extended by the value of a stroke s , the section is turned by an angle ϕ_P , which can be determined from the triangle ABO (Fig. 3)

$$\phi_P = \gamma - \gamma_0, \tag{1}$$

where γ – central angle between supports of the hydraulic cylinder in the end position of rod extension, that is at $L_{W_{max}} = L_0 + L_m$;

γ_0 – central angle between supports of hydraulic cylinders in the start position of rod extension, that is at $L_{W_{min}} = L_0$.

$$\gamma = \arccos \frac{\frac{D_{PL,HC}^2 + D_{PL,ROD}^2}{2} - 2 \cdot (L_0 + L_m)^2}{D_{PL,HC} \cdot D_{PL,ROD}}, \tag{2}$$

$$\gamma_0 = \arccos \frac{\frac{D_{PL,HC}^2 + D_{PL,ROD}^2}{2} - 2L_0^2}{D_{PL,HC} \cdot D_{PL,ROD}}, \tag{3}$$

where $D_{PL,HC}$ – diameter of a circle formed by placed hydraulic cylinder trunnions on the shell ring of the tail section, m; $D_{PL,ROD}$ – diameter of a circle of rod trunnion rotation on the head section, m; L_W – spacing between body trunnions and hydraulic cylinder rod, provided that rod extension is maximum, m; L_0 – spacing between body trunnions and folded up hydraulic cylinder (minimal extension), m.

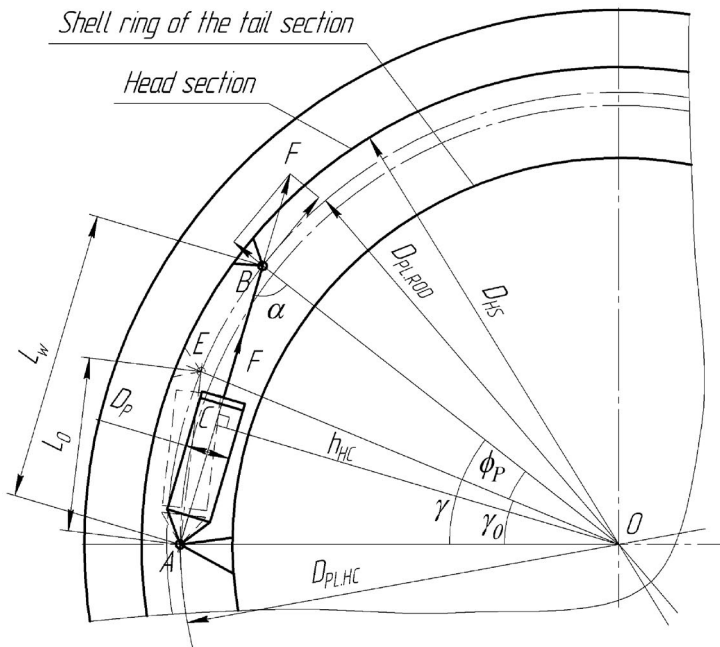


Fig. 3. Explanatory design to determine the angle of rotation of the head section of geokhod

After substitution of (Eq. 2) and (Eq. 3) into (1) we obtain

$$\varphi_{II} = \arccos \frac{\frac{D_{PL.HC}^2 + D_{PL.ROD}^2}{2} - 2 \cdot (L_0 + L_m)^2}{D_{PL.HC} \cdot D_{PL.ROD}} - \arccos \frac{\frac{D_{PL.HC}^2 + D_{PL.ROD}^2}{2} - 2L_0^2}{D_{PL.HC} \cdot D_{PL.ROD}}, \quad (4)$$

If body trunnions and hydraulic cylinder rods are placed on the same circle, that is, $D_{PL.ROD} = D_{PL.HC} = D_{HC}$ the angle of rotation φ_P is determined by the expression

$$\begin{aligned} \varphi_P &= \arccos \frac{D_{HC}^2 - 2 \cdot (L_0 + L_m)^2}{D_{HC}^2} - \arccos \frac{D_{HC}^2 - 2L_0^2}{D_{HC}^2} = \\ &= \arccos \left(1 - \frac{2 \cdot (L_0 + L_m)^2}{D_{HC}^2} \right) - \arccos \left(1 - \frac{2L_0^2}{D_{HC}^2} \right). \end{aligned} \quad (5)$$

3 Determination of the angular rate of head section rotation

If consumption of hydraulic fluid passing into the head end of a hydraulic cylinder is constant $Q(t) = const$, piston and rod will be extended at a constant rate v , determined from the expression

$$v = \frac{Q}{S_p}, \quad (6)$$

where $S_p = \pi \cdot D_p^2 / 4$ – area of a hydraulic cylinder piston, m^2 ; D_p – diameter of a hydraulic cylinder piston, m ;

Extension of hydraulic cylinder rod (Fig. 3) from the start position is determined according to the formula

$$\delta(t) = vt = \frac{Q}{S_p} \cdot t. \quad (7)$$

The angle of rotation of the head section is $\varphi_p(t)$, as time variable t varies from L_0 to $L_0 + L_m$ when rod is extended, as it is stated in (Eq. 5)

$$\varphi_p(t) = \arccos \frac{\frac{D_{PL.HC}^2 + D_{PL.ROD}^2}{2} - 2 \cdot (L_0 + \delta(t))^2}{D_{PL.HC} \cdot D_{PL.ROD}} - \gamma_0, \quad (8)$$

where $\gamma_0 = const$ – angle, determined according to the formula (Eq. 3);

The angular rate of section rotation $\omega(t)$ is formulated in the expression

$$\omega(t) = \frac{d\varphi_p(t)}{dt}, \quad (9)$$

After differentiating the expression (Eq. 8) with respect to time we obtain

$$\omega(t) = \frac{4v \cdot (L_0 + vt)}{D_{PL.HC} \cdot D_{PL.ROD} \cdot \sqrt{1 - \left(\frac{\frac{D_{PL.HC}^2 + D_{PL.ROD}^2}{2} - 2 \cdot (L_0 + vt)^2}{D_{PL.HC} \cdot D_{PL.ROD}} \right)^2}}, \quad (10)$$

After differentiating the expression (Eq. 4) by analogy we obtain

$$\omega(t) = \frac{4v \cdot (L_0 + vt)}{D_{HC}^2 \cdot \sqrt{1 - \left(1 - \frac{2 \cdot (L_0 + vt)^2}{D_{HC}^2}\right)^2}}, \tag{11}$$

In terms of the expressions (Eq. 10) and (Eq. 11), the angular rate of head section rotation $\omega(t)$, as well as the turning moment made by transmission will change according to hydraulic cylinder rod extension (Fig. 4). Provided that hydraulic fluid passing into the head end $Q(t) = const$ the rate of piston movement is constant too $v(t) = const$, but the circular rate v_R will change and determine variation of angular rate of head section rotation.

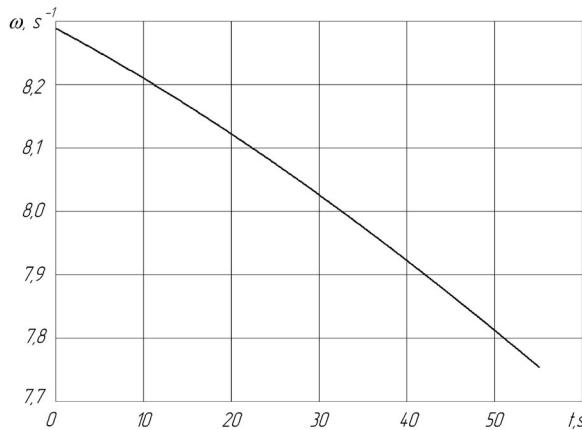


Fig. 4. The variation graph of angular rate of head section rotation during the time t of rod extension

It is evident that to obtain a uniform angular rate ($\omega(t) = const$) during the period of cylinder rod extension the rate of extension $v(t)$ is to vary according to a certain law. After expressing the rate $v(t)$ in terms of (Eq. 11) we have

$$v(t) = \frac{\sqrt{4D_{HC}^2 - 4L_0^2 + (D_{HC} \cdot \omega \cdot t)^2} - L_0 \cdot \omega \cdot t}{4 + \omega^2 \cdot t^2} \cdot \omega \tag{12}$$

As it is stated in the known expression, the circular rate of head section rotation will be calculated as the product of rotation radius – R and angular rate – ω

$$v_R = R \cdot \omega, \tag{13}$$

A circular rate will be determine by the rate of hydraulic cylinder rod extension and angle α between the vector of the rod rate v and angular rate v_R (tangent drawn to the circle of rotation)

$$v_R = v \cdot \cos \alpha, \tag{14}$$

After expressing v from (Eq. 14) and substituting it for v_R in the expression (Eq. 13) we have

$$v = \frac{R}{\cos \alpha} \cdot \omega, \tag{15}$$

In the expression (Eq. 15) the first multiplier is a ratio

$$\frac{R}{\cos \alpha} = \frac{\sqrt{4D_{HC}^2 - 4L_0^2 + (D_{HC} \cdot \omega \cdot t)^2} - L_0 \cdot \omega \cdot t}{4 + \omega^2 \cdot t^2}, \tag{16}$$

In addition, it is to say, that in expressions (Eq. 12) and (Eq. 16) the product $\omega \cdot t$ is an angle of rotation, that is, $\varphi_p = \omega \cdot t$.

We can obtain the necessary variation of rod extension rate if we change the volume of hydraulic fluid passing into the head end of the cylinder per time unit, that is, by changing the consumption according to the expression $Q = v \cdot S_{II}$.

$$Q(t) = \frac{\sqrt{4D_{HC}^2 - 4L_0^2 + (D_{HC} \cdot \omega \cdot t)^2} - L_0 \cdot \omega \cdot t}{4 + \omega^2 \cdot t^2} \cdot \omega \cdot \frac{\pi \cdot D_p^2}{4} \quad (17)$$

Figure 5 demonstrates the graph of changing hydraulic fluid consumption for one hydraulic cylinder

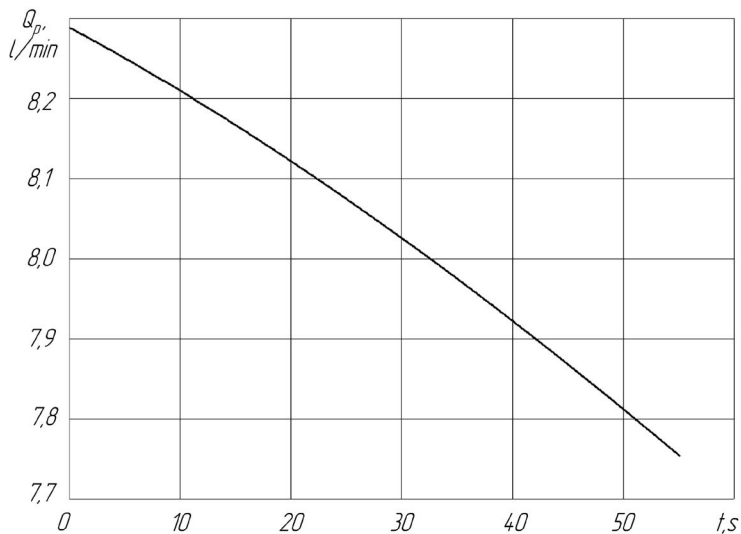


Fig. 5. The graph of changing hydraulic fluid consumption in the head end of the hydraulic cylinder during the time of rod extension t

Therefore, the angular rate of rotation of transmission output element (head section of geokhod) is constant provided that hydraulic fluid consumption in each cylinder varies according to the set variable (Eq. 17). Volumetric and throttling regulating can be utilized to provide the consumption of hydraulic fluid according to the set variable [15]. Volumetric feeder with stepping motor drive system is an alternative.

4 Conclusions

1. The angular rate of output element rotation changes periodically in rotary transmission tooled with hydraulic cylinders placed on chords, provided that hydraulic fluid consumption in hydraulic cylinders is constant. It is caused by changing attitude position of hydraulic cylinder rods (similar to turning moment irregularity). Additional research is required to evaluate kinematic irregularity.

2. Hydraulic fluid consumption is to vary according to a certain law in each hydraulic cylinder in order to provide regular rotation of output element in rotary transmissions tooled with hydraulic cylinders placed on chords. It is possible to achieve quite simple – with the use of volumetric feeders, proportional control, and other throttling regulating methods.

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