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RESEARCH OF RECIPROCATING SPEED OF THE RODS SUSPENSION POINT IN THE LOW-SPEED OPERATION MODE OF THE MECHANICAL TRANSMISSION OF THE NEW CONSTRUCTIVE SOLUTION OF THE SUCKER-ROD PUMP

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Abstract. The article investigates the problem of determining the number of swings of the rods suspension point of the new constructive solution of the sucker-rod pumping unit in the low-speed operation mode. It was determined that this small value of the speed causes a decrease in the maximum kinetic energy caused by the mechanical transmission of the rod well pump, and therefore, considering this energy parameter of the system as an analyzed parameter is of great practical importance. Therefore, in the article, as a criterion for the low-speed operation mode, a comparison of the maximum kinetic energy of the pumping unit and the useful energy spent on lifting of the liquid from the well was proposed. It was determined that with the increase in the diameter of the plunger, the useful energy used on lifting the liquid from the well increases, and accordingly, the share of kinetic energies in the total used energy balance increases accordingly.

Key words: *pumping unit, plunger, kinetic energy, reciprocating speed, operation mode.*

Introduction. At all stages of the economic development of many countries, the oil industry is the most important and attention-grabbing sector. It is impossible to develop the general development plan of the state and predict its future development stages without taking into account the situation and opportunities of this field. One of the most important places in the economic development of our republic is the extraction and transportation of the oil to the global world market. From this point of view, there is a great need to research and create new constructions of sucker-rod pumping units used in oil extraction [1, 2, 3].

Taking into account the mass of sucker-rod pumping unit in use, one of the urgent issues is either their improvement or the creation of new constructive solutions with a more perfect construction [6, 7, 8, 9, 10, 11].

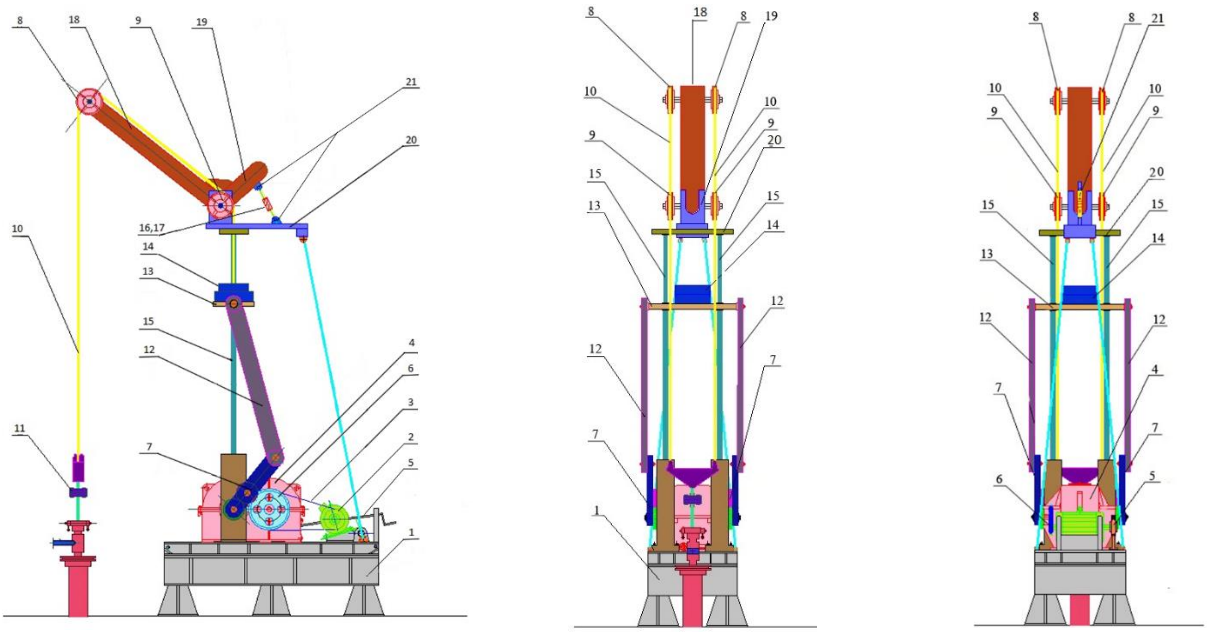
Therefore, in order to ensure the stable operation of the mechanical drive of the sucker-rod pump and save energy, as well as to reduce the overall dimensions and increase the reliability at the Department of "Mechatronic and machine design" of Azerbaijan Technical University were developed the new constructive solution of beamless sucker-rod pumping unit [15], the originality of the construction is approved by Eurasian Patent Organization №039650 [4], 2022 and the Intellectual Property Agency of the Republic of Azerbaijan № a2019 0162, 2021 [5].

At Figure 1 shown the overview of the new constructive solution of the sucker-rod pumping unit. The new constructive solution of the sucker-rod pumping unit consist from frame (1), three-phase short-circuited asynchronous motor (2), V-belt drive (3), rigidly connected two-flow three-stage re-ducer (4), on the drive shaft of which on one side mounted double-shaped brake (5) and on the other side V-belt pulley (6), and on the driven shaft of its installed two cranks (7); guide blocks (8, 9), ropes (10) connected to the rods suspension point. The converting mechanism, which consists of two slider-crank linkage (12), converts the rotational motion of the crank into the upstroke and down-stroke movement of the rod suspension point. The mechanical transmission has counterweights whose weight can be adjusted (14), located on a movable cross beam (13), which is connected with hinge joint to the connecting-rod.

The guide blocks are surrounded by a flexible rope, one end of which is connected to the mova-ble beam, and the other end is connected to the rods suspension point. In addition, the mechanical drive has a guide system consisting of two vertically located cylindrical tubes (15) and the movable beam. The mechanical transmission has articulated front (18) and rear (19) arms, which can be ad-justed by using (16,17) screw tensioners, a fixed cross beam (20) rigidly connected to the guide tubes. The screw tensioner (21) is connected to the frame of the construction, as well as to the joints with the front and rear arms [14, 16].

The working principle of mechanical transmission is as follows: After the three-phase asynchronous motor is started, the step pulley of the V-belt drive rotates and drives the driven pulley mounted on the drive shaft of the multi-step reducer. The required rotational motion is supplied to the driven shaft of the multi-stage reducer. At the same time, the cranks mounted on the driven shaft of the reducer also rotate; a movable cross beam and an adjustable counterweights located on it moves up and down. Guide blocks installed on the immovable transverse beam and front arm of the device surrounded by a flexible rope on both sides, in turn, participate in moving the rods suspension point, in other words, the piston of the well up and down. In this case, the stroke of the rods suspension point, its speed and acceleration are closer to the ideal law.

The laboratory model of the mechanical transmission which consist from transforming mechanism, ropes, cranks and a reducer, has been developed and tested.



a) *b)* *c)*

Fig. 1. New constructive solution of beamless pumping unit consisting of an slider-crank mechanism and a rope-block system: a - side view; b - front view; c - rear view

Formulation of the problem. During the operating sucker rod pump, the pumping unit is affected by the gravity force of the rods column, the gravity force of the liquid column, the resistance force caused by the friction of the rods column against the well walls (edge friction), the resistance force to the movement of the rod column due to friction inside the viscous fluid, the friction force in the reducer and forces that create torque in the engine of the mechanical transmission. As a result of studies, it has been determined that the role of other forces (frictional forces in the joints, etc.) affecting the pumping unit is insignificant and their influence can be ignored.

The boundary friction force caused by the friction of the rods column against the walls of the pump-compressor pipes is determined depending on the diameters of the pipes and rods, well path and the lubrication properties of the fluid. At low speeds, the viscous (hydrodynamic) friction force is determined depending on the relative speed of the rod column and the liquid, as well as the viscosity of the liquid in the riser pipes.

At present, asynchronous motors with a short-circuited rotor with a high starting torque are used in the transmission of the pumping unit. It is known that these motors have rigid mechanical characteristics, that is, the angular speed of the electric motor rotor during operation is very little dependent on the load. Such engines have a significant power reserve to overcome possible overloads when starting the mechanical transmission of the sucker-rod pump, the balancing of its rotor practically doesn't depend on the number of swings per minute of the transmission. Therefore, it is considered that the speed of the rods column and the resistance forces generated during its movement do not depend on balancing. That is, the work of frictional forces is constant and not related to balansing.

Forces of gravity are potential forces, so the work done by gravity forces in one cycle of the pumping unit is always zero. Therefore, these forces don't depend on equilibrium [12, 13].

Research method. During the operation of the mechanical transmission of the sucker-rod pump, its rods column, plunger pump, pulleys, cross beams, connection rod, cranks, balancing counterweights, gears of the reducer, belts and the rotor of the electric motor are in motion. Therefore, the kinetic energy of the mechanical transmission of the sucker-rod pump consists of the sum of the kinetic energies of these elements [6, 7, 9, 10]:

$$E_{ms} = E_{rd} + E_{pul} + E_{beam} + E_{cr} + E_{crank} + E_{cw} + E_{gd} + E_{belt} + E_{rot}$$

It is known that sucker-rod pumping units work at low speeds. That is, the number of swings per minute of the rod suspension point doesn't exceed 10….15 min^{-1}. Therefore, this small value of the speed causes a decrease in the maximum kinetic energy caused by the mechanical transmission of the sucker-rod pump, and therefore it has great practical importance to consider this energy parameter of the system as an analyzed parameter.

Therefore, the article suggests comparing the maximum kinetic energy of the pumping unit and the useful energy spent on lifting the liquid from the well as a criterion of the low-speed operation mode.

In order to simplify the calculations and make the results obtained more convenient for engineering calculations, we assume that the mass of the rods column and counterweights are significantly greater than the mass of other parts of the pumping unit. Therefore, we can determine the kinetic energy of the system for the proposed new constructive solution of the beamless sucker-rod pumping unit as follows:

$$E_{ms} = E_{rd} + E_{cw}$$

there E_{rd}, E_{cw} - are the kinetic energies of the rods column, the cross beam, and the counterweights, respectively.

Kinetic energy of a rods column of the new constructive solution of the sucker-rod pumping unit:

$$E_{rd} = \frac{\rho_{rd} \cdot A_{rd} \cdot L \cdot v^2}{2} = \frac{\rho_{rd} \cdot \frac{\pi \cdot d_{rd}^2}{4} \cdot L \cdot (\omega \cdot r)^2}{2} = \frac{\rho_{rd} \cdot \frac{\pi \cdot d_{rd}^2}{4} \cdot L \cdot (2 \cdot \pi \cdot n)^2 \left(\frac{S_{rd}}{2}\right)^2}{2} = $$
$$= \frac{\rho_{rd} \cdot d_{rd}^2 \cdot L \cdot \pi^3 n^2 \cdot S_{rd}^2}{8}$$

there ρ_{rd} - rods material density; A_{rd} - cross-sectional area of the rod; L - well depth; v -speed of the rods suspension point; n -number of the swings of the rods suspension point; S -stroke of the rods suspension point.

For the movable counterweight balancing method, we use the condition of equality of the performed work during the upstroke and downstroke movement of the rods suspension point to determine the kinetic energy generated by the action of counter loads. Thus, for movable counterweight balancing method, the work spent by the engine during the upstroke and downstroke movement of the rods suspension point is:

$$A_{up} = (G_{rd} + G_{lq})S_{rd} - G_{cw}S_{cw} \tag{1}$$

$$A_{dw} = -G_{rd}S_{rd} + G_{cw}S_{cw} \tag{2}$$

If we take the work done during the upstroke and downstroke movement equally to each other

$$(G_{rd} + G_{lq})S_{rd} - G_{cw}S_{cw} = -G_{rd}S_{rd} + G_{cw}S_{cw}$$

If $S_{rd} = S_{cw} = 2r$ and $S_r = 2R$, then

$$r\left(G_{rd} + \frac{G_{lq}}{2}\right) - G_{cw}r = 0$$

If we finde weight of the movable counterweights from the last expression:

$$G_{cw} = \left(G_{rd} + \frac{G_{lq}}{2}\right) \tag{3}$$

Then the kinetic energy generated by the action of movable counterweights:

$$E_{cw} = \frac{\left(\left(G_{rd} + \frac{G_{lq}}{2}\right)\right)v^2}{2} = \frac{\left(\rho_{rd} \cdot \frac{\pi \cdot d_{rd}^2}{4} \cdot L + \rho_{lq} \frac{\pi \cdot D_{pl}^2}{8} H_d\right)v^2}{2} = \tag{4}$$
$$= \frac{(2\rho_{rd} \cdot d_{rd}^2 \cdot L + \rho_{lq} D_{pl}^2 H_d)\pi^3 n^2 S_{rd}^2}{16}$$

Therefore, we can define the kinetic energy of the system for the proposed new constructive solution of the beamless sucker-rod pumping unit as follows:

$$E_{ms} = \frac{\rho_{rd} \cdot d_{rd}^2 \cdot L \cdot \pi^3 n^2 \cdot S_{rd}^2}{8} + \frac{(2\rho_{rd} \cdot d_{rd}^2 \cdot L + \rho_{lq} D_{pl}^2 H_d)\pi^3 n^2 S_{rd}^2}{16} = \tag{5}$$

$$= \frac{\left(4\rho_{rd} \cdot d_{rd}^2 \cdot L + \rho_{lq} D_{pl}^2 H_d\right)\pi^3 \cdot n^2 \cdot S_{rd}^2}{16}$$

And the useful energy used to lifting of liquid:

$$E_{us} = \left(G_{lq} - G_{as}\right)S_{rd} = \frac{\pi}{4} \cdot D_{pl}^2 \cdot S_{rd}\left(\rho_{lq} \cdot L - \rho_{as} \cdot H_d\right)g \tag{6}$$

there ρ_{rd} - density of lifting liquid; ρ_{as} - density of lifting liquid at annular space; D_{pl} -diametr of the plunger; H_d - dynamic level height.

If we assume that the kinetic energy of the system is significantly less than the useful energy, then to determine the minimum number of swings of the rods suspension point of the sucker-rod pumping unit, we take the following expression

$$n = \sqrt{\frac{4 \cdot D_{pl}^2 \cdot \left(\rho_{lq} \cdot L - \rho_{as} \cdot H_d\right) \cdot g}{\left(4\rho_{rd} \cdot d_{rd}^2 \cdot L + \rho_{lq} D_{pl}^2 H_d\right) \cdot \pi^2 \cdot S_{rd}}} \tag{7}$$

For example, if the density of the liquid is 900 kg/m^3, the density of the rod material is 7800 kg/m^3, well depth is 1000 m, the diameter of the plunger is 70 mm, the diameter of the rod column is 19 mm, density of lifting liquid at annular space is 800 kg/m^3, the dynamic level is 200 m, if the stroke of the rods suspension point is 3,0 m, then the maximum number of oscillations per minute, which ensures the low speed operation mode of the pumping unit, will be 4,87. For comparison, the number of oscillations per minute in the static mode according to the Cauchy criterion corresponds to 16,7, which is significantly greater than its minimum value [14, 16, 17].

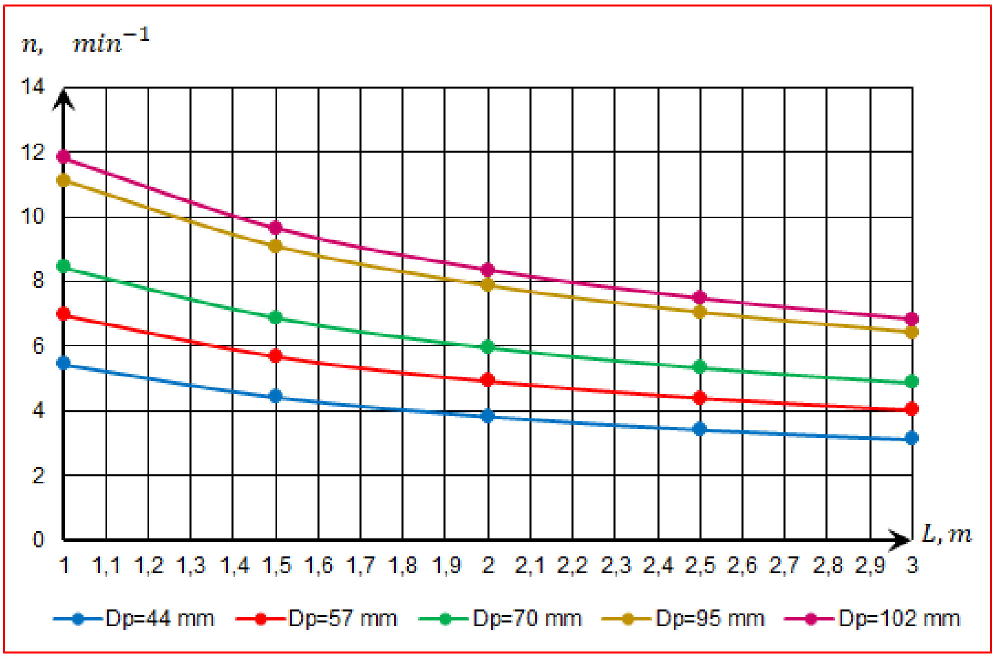


Fig. 2. Graph of the dependence of the reciprocating speed characterizing the low-speed operation mode of the sucker-rod pumping unit on the stroke of the rods suspension point

Figure 2 shows the graph of the dependence of the reciprocating speed characterizing the low-speed operation mode of the sucker-rod pumping unit on the stroke of the rods suspension point. As can be seen from the graph, with the increase in the diameter of the plunger, the useful energy used to lift the liquid from the well increases, and accordingly, the share of kinetic energies in the total balance of the energy used increases accordingly.

Results and conclusions. In the article, analytical expressions were proposed to determine the minimum reciprocating speed of the rods suspension point in the low-speed operation mode of the mechanical transmission of the new constructive solution of the sucker-rod pump. It was determined that the low-speed of the rods suspension point causes the decrease in the maximum kinetic energy caused by the mechanical transmission of the sucker-rod pump, and therefore it is of great practical importance to consider this energy parameter of the system as an analyzed parameter. Therefore, in the article, as a criterion for the low-speed operation mode, a comparison of the maximum kinetic energy of the pumping unit and the useful energy spent on lifting of the liquid from the well was proposed. It was determined that with the increase in the diameter of the plunger, the useful energy used on lifting the liquid from the well increases, and accordingly, the share of kinetic energies in the total used energy balance increases accordingly.

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