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KINEMATIC ANALYSIS OF THE CONVERTING MECHANISM OF INNOVATIVE BEAMLESS PUMPING UNIT FOR OIL INDUSTRY

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Abstract. The article discusses the design of an innovative beamless pumping unit for mechanization of onshore oil production. The design of the innovative beamless pumping unit was analyzed, as well as a kinematic analysis of the converting mechanism of the pumping unit and analytical expressions were proposed to determine the actual movement of the rods suspension point. The proposed analytical expressions allow us to determine the main kinematic parameters for a new structural solution of the pumping unit.

Keywords. Pumping unit, rods column, rods suspension point, displacement.

Introduction. One of the most important places in the independent economic development of countries such as the Republic of Azerbaijan, the Russian Federation and the Republic of Kazakhstan, which were members of the former Soviet Union, is occupied by the oil industry.

From this point of view, there is a great need to research and create new constructions of pumping units used in oil extraction. The efficiency of oil production mainly depends on the type of used equipment. At present, beam sucker-rod pumping units are widely used as more sophisticated and effective equipment in oil extraction. This equipment remains an integral part of the oil production complex. The sucker-rod pumping unit are intended to provide forward movement to the depth pump installed at the bottom of the well. In order to reduce energy losses, this equipment must have a perfect kinematic scheme [1, 2, 3].

Recently, there has been quite a lot of interest in the use of new construction of beamless pumping units along with beam sucker-rod pumps. The construction of the newly created pumping unit should have a simple, economical, and compact construction. Taking into account the influence of the mentioned factors, at the department of "Machine design and industrial technologies" of the Azerbaijan Technical University the construction of a new construction of a beamless sucker-rod pumping unit was developed (Eurasian patent №032268) [4].

Formulation of the problem. During the upward and downward strokes of the plunger, the functionality of depth pumps is observed by altering the movement direction of the rod's column. Consequently, within a single cycle, the path of the rod's suspension point undergoes changes in both its direction and velocity, along with variations in speed and acceleration. Consequently, the dynamic forces acting on the rod are influenced by the displacement, speed, and acceleration of the suspension point of the rod. The laws governing the motion of the rod's suspension point are contingent upon the kinematic arrangement of the employed pumping unit. As customary in the kinematic analysis of any linkage mechanism, the primary objective is to ascertain the states, velocities, and accelerations of individual points and components. In the context of our investigation, focusing on a novel design of a beamless pumping unit, our interest lies in understanding the pattern of change in the displacement of the rod's suspension point.

Figure 1 shows the scheme of innovative beamless sucker-rod pump [5].

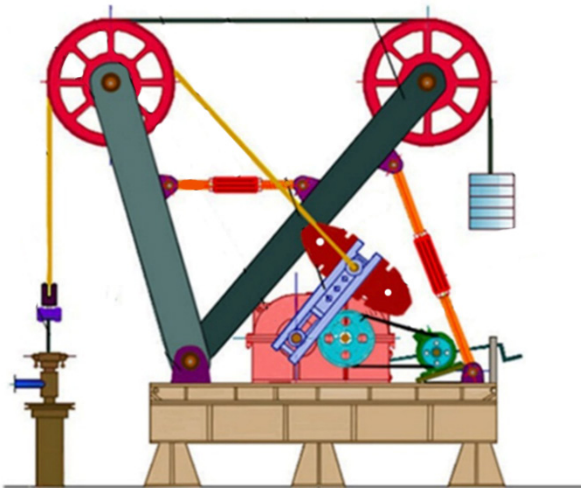

Figure 1. Scheme of innovative beamless pumping unit

Solution of the problem.

It is known that the displacement of the rods suspension point, its speed and acceleration changes in one full cycle of the crank of the pumping unit. Therefore, the regularity of the movement of the rods suspension point depends on the kinematic scheme of the converter mechanism of the pumping unit (figure 2). It is known that the purpose of conducting a kinematic analysis of any linkage mechanism is to determine the displacement, speed and acceleration of their various points and links.

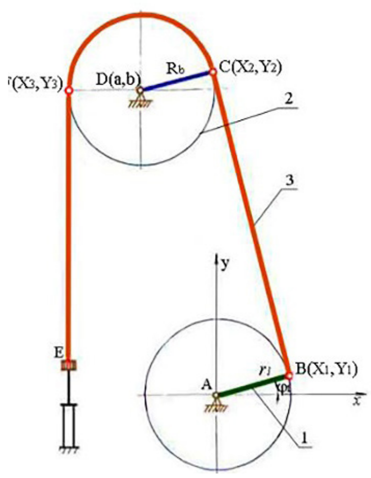

Figure 2. Calculation scheme of the converting mechanism of the innovative beamless pumping unit

If we take the length of the elbow to be r_1, then the distance traveled by the suspension point of the bar is $S = 2r_1$. As can be seen from the scheme, the corresponding displacement of the rods suspension point will be equal to the displacement of the corresponding point of the rope. During the kinematic research, the length of the elbow $AB = r_1$, its turning angle φ_1, the radius of the block $DC = R_b$, the coordinates $A(0,0)$, $D(a,b)$ of the points A and D and the total length L of the rope are given. The goal is to find the displacement (path) of point E depending on the angle of rotation of the crank.

How as can we see from the construction of the device that the displacement of the point E depends on the change of the distance BC and the arc length $\breve{C}F$ of the block. That is, $(S_E = f\left(BC + \breve{C}F\right)$. So, to solve the problem, it is required to find the distance from point B of the crank to point C, where the rope touches the block, and the length of the arc covered by the rope, that is, the length from point C to point F.

Since the generalized coordinate φ_1 is known

$$\begin{aligned} x_1 &= r_1 \cdot cos\varphi_1 \\ y_1 &= r_1 \cdot sin\varphi_1 \end{aligned} \tag{1}$$

To solve this problem, it is necessary to find the length of the line BC tangent to the known circle with radius R_b from the given point $B(x_1, y_1)$. In other words, we need to find the distance

$$BC = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{2}$$

The coordinates x_2 and y_2 are the unknown coordinates of the point C, which is the point of contact of the straight line BC with the circle of radius R_b. To determine them, we first write the equation of the circle:

$$(x-a)^2 + (y-b)^2 = R_b^2 \tag{3}$$

The coordinates a and b are the known coordinates of the center of the circle with radius R_b. Coordinates x_2 and y_2 located on this circle must satisfy the equation (3). So it should be $(x-a)^2 + (y-b)^2 = R_b^2$

Let's write the equation of the straight line BC passing through the point $B(x_1, y_1)$

$$y - y_1 = k(x - x_1) \tag{4}$$

Since this straight line passes through point $C(x_2, y_2)$, the coordinates x_2 and y_2 must satisfy the equation (4).

$$y_2 - y_1 = k(x_2 - x_1) \tag{5}$$

here k – is the angular coefficient, we find it from the derivative of equation (3) in a non-obvious form.

$$y' = \frac{a-x}{y-b} \tag{6}$$

From (5) equation

$$k = \frac{y_2 - y_1}{x_2 - x_1} \tag{7}$$

From other side

$$k = f'(x_2) = \frac{a - x_2}{y_2 - b} \tag{8}$$

That is means:

$$\frac{a - x_2}{y_2 - b} = \frac{y_2 - y_1}{x_2 - x_1} \tag{9}$$

From other side

$$(x_2 - a)^2 + (y_2 - b)^2 = R_b^2 \tag{10}$$

From the together slowing of the equations (9) and (10) we get:

$$\begin{cases} x_2^2 + y_2^2 - x_2(a + x_1) - y_2(b + y_1) + ax_1 + by_1 = 0 \\ x_2^2 + y_2^2 - 2x_2a - 2y_2b + a^2 + b^2 - R_b^2 \ \ = 0 \end{cases} \tag{11}$$

If we subtract side by side to determine the x_2 and y_2 coordinates in this system equation and do some simplification, we get the following expression

$$x_2(a - x_1) = a^2 + b^2 - R_b^2 - ax_1 - by_1 - y_2(b - y_1) = 0$$

there if we substitute $(a - x_1) = N$; $(b - y_1) = M$ and $a^2 + b^2 - R_b^2 - ax_1 - by_1 = P$, then

$$x_2N = P - y_2M \quad \Rightarrow x_2 = \frac{P}{N} - y_2\frac{M}{N}$$

if $\frac{P}{N} = n$ and $\frac{M}{N} = m$ then

$$x_2 = n - y_2m$$

If we consider x_2 in equation (11,b), then

$$(n - y_2m)^2 + y_2^2 - 2(n - y_2m)a - 2y_2b + a^2 + b^2 - R_b^2 = 0$$

If we simplify this expression, then we get the following:

$$y_2^2\left(m^2 + 1\right) + (2ma - 2mn - 2b)y_2 + n^2 -$$

$$-2an + a^2 + b^2 - R_b^2 = 0$$

if we substitute $\left(m^2 + 1\right) = A$; $(2ma - 2mn - 2b) = B$ and $n^2 - 2an + a^2 + b^2 - R_b^2 = C$ then we will get:

$$Ay_2^2 + By_2 + C = 0$$

And the roots of this equation,

$$y_{2(1,2)} = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \tag{12}$$

Then

$$x_{2(1,2)} = n - \left(\frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \right) m \qquad (13)$$

Now let's find $\breve{C}F$ is the length of the arc covered by the rope:

$$\breve{C}F = \int_{x_2}^{x_3} \sqrt{1 - \left(f'(x) \right)^2} dx \qquad (14)$$

if we substitute $f'(x) = y'(x)$. To find $y'(x)$, we solve the equation of the circle (3) based on y:

$$y = b \pm \sqrt{R_b^2 - x^2 + 2ax - a^2}$$

If we solve this equation for x, we get

$$y'(x) = \frac{(a-x)}{\sqrt{R_b^2 - x^2 + 2ax - a^2}}$$

Then the formula (14) will transform to the fallowing form:

$$\breve{C}F = \int_{x_2}^{x_3} \sqrt{1 + \frac{(a-x)^2}{R_b^2 - x^2 + 2ax - a^2}} dx =$$

$$= \int_{x_2}^{x_3} \frac{1}{\sqrt{1 - \left(\frac{x-a}{R_b} \right)^2}} dx \qquad (15)$$

If accept like $t = \frac{x-a}{R_b}$; $dt = \frac{1}{R_b} dx$ and $dx = R_b dt$,

then we will get following formula:

$$\breve{C}F = \int_{x_2}^{x_3} \frac{1}{\sqrt{1-t^2}} R_b dt =$$

$$= R_b \left[arcsin \frac{x_3 - a}{R_b} - arcsin \frac{x_2 - a}{R_b} \right] \qquad (16)$$

After determining both the coordinates x_2 and y_2 coordinates and the length of the arc with which the rope covers the block, the displacement of point E – rods suspension point, can determined like that:

$$S_E = \left(BC_{max} + \breve{C}F(\varphi)_{max} \right) - \left(BC(\varphi)_1 + \breve{C}F(\varphi)_1 \right)$$

Results.

In the article, the advantages and disadvantages of the existing classic beam sucker-rod pumping units, which used in the oil industry are analyzed, and the construction and working principle of the new solution of beamless pumping unit are explained in order to overcome these shortcomings. The proposed at the article analytical expressions allow to determine its main kinematic parameters during the synthesis and analysis of the converter mechanism of the new constructive solution of beamless sucker-rod pumping unit. By this expressions allow to more accurately determine the actual value of the displacement of the rods suspension point of the this pumping unit, as well as it the productivity.

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КИНЕМАТИЧЕСКИЙ АНАЛИЗ ПРЕОБРАЗУЮЩЕГО МЕХАНИЗМА ИННОВАЦИОННОГО БЕЗБАЛАНСИРНОГО СТАНКА КАЧАЛКИ ДЛЯ НЕФТЯНОЙ ПРОМЫШЛЕННОСТИ

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Аннотация. В статье рассмотрена конструкция инновационного безбалансирного станка-качалки, предназначенное для механизации добычи нефти на суше. Был произведён анализ конструкции инновационного станка-качалки, а также кинематический анализ преобразующего механизма станка-качалки и предложены аналитические выражения для определения фактического перемещения точки подвеса штанги. Предложенные аналитические выражения позволяют определить основные кинематические параметры для нового конструктивного решения станка-качалки.

Ключевые слова. Станок-качалка, колонна штанг, точка подвеса штанг, перемещение.