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THE DESIGNING OF CRANK MECHANISM OF PISTON PUMP

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Наведені розрахунки оптимального зміщення вісі валу кривошипу відносно осі поршня насосу, що застосовується для перекачування трубопроводами різноманітних рідин у нафтовій, газовій та нафтохімічній галузях промисловості

Ключові слова: насос, кривошип, поршень, зусилля

Приведены расчеты оптимального смещения оси вала кривошипа относительно оси поршня насоса, который используется для перекачивания трубопроводами различных жидкостей в нефтяной, газовой и нефтехимической отраслях промышленности

Ключевые слова: насос, кривошип, поршень, сила

1. Introduction

Due to simplicity and reliability of work, piston pumps are widely adopted in petroleum, gas and petrochemical industries, all the technical processes of which are connected with re-pumping of different liquids (oil, petrochemical products, liquid petroleum gas, water, clay solutions, chemical reagent, etc.) through the pipelines.

2. The overview of recent research sources and publications

The piston pumps are widely used in the oil and gas well drilling. They are used for making the circulation of clay solutions or water in the oil well.

The piston pumps are mainly used in oil production for transportation of oil from the well, re-pumping of water and oil of great viscosity through the pipeline, hydraulic rupture of layers and water forcing into the layer [1, 2, 3].

3. The description of previously unsolved parts of the problem

As there is not any area in petroleum industry where the pumps wouldn't be used, the further improvement of their technical and economic indicators remains to be the main problem of petroleum industry. The reservation of efficiency during the work and full usage of installed capacity are the most important tasks of service staff.

4. Setting of the task

The axis of crank shaft, the construction of which is represented by us, is shifted down relatively to axis of piston on purpose of transverse force's reduction which affects the piston's slider during the pumping action. The quantity of deflection e will be optimal when the transverse force F_y which is represented in fig. 1, is a minimum share of maximum axial working force F_x^{max}.

To solve this task it is necessary to make up a formula of change efforts of transverse F_x during the pump work cycle, which includes quantity e, after that using this formula with the help of PC to find the value e which corresponds the lowest level of maximum value F_y of each shift.

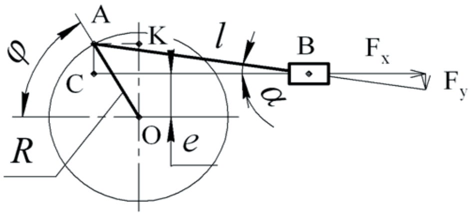


Fig. 1. The scheme of calculation of the optimal value e

5. Basic material and results

The value of the transverse force F_y which affects the piston slider (according to figure 1) equals

$$F_y = F_x \cdot \text{tg}\alpha \, , \tag{1}$$

where F_x – is the value of working force that affects the pump piston during the tact injection (tact of absorption is not included to the calculation because of the fact that the absorption of pressure doesn't exceed 0,1 MPa and is less than the injection tact), this quantity depends on the supply pressure p_φ and piston area F_n, that is

$$F_x = p_\varphi \cdot F_n \, , \tag{2}$$

where α – variable during the injection tact, angle of the tilt of the connecting rod l to the horizontal.

This angle is defined from the triangle ABC (fig. 1)

$$\sin\alpha = \frac{AC}{AB} = \frac{KO - e}{l} = \frac{R \cdot \sin\varphi - e}{l}. \qquad (3)$$

So,

$$\alpha = \arcsin\left(\frac{R \cdot \sin\varphi - e}{l}\right). \qquad (4)$$

Substituting the values (4) in formula (1) we will get:

$$F_y = F_x \cdot tg\left[\arcsin\left(\frac{R \cdot \sin\varphi - e}{l}\right)\right]. \qquad (5)$$

After the substitution into expression (5) formulas (2) and (7), [4] we will get:

$$F_y = \frac{10^3 \cdot F_n \cdot V_{np} \cdot tg\left[\arcsin\left(\frac{R \cdot \sin\varphi - e}{l}\right)\right]}{V_0 - F_n \cdot \left(R \cdot (1 - \cos\varphi) - \left[l - \sqrt{l^2 - (R \cdot \sin\varphi - e)^2}\right] - \frac{h_n}{2\pi} \cdot \varphi\right)}. \qquad (6)$$

Since the α angle of the tilt of the connecting rod l from the horizontal in the tact of injection with the displacement of the axis of the crank shaft doesn't exceed 6^0, the quantity tgα differs very little from sinα, so for a given case it can be considered that tg$\alpha \approx$ sinα, then

$$tg\left[\arcsin\left(\frac{R \cdot \sin\varphi - e}{l}\right)\right] \approx \frac{R \cdot \sin\varphi - e}{l}. \qquad (7)$$

After the substituting of this value into expression (6) we will finally get:

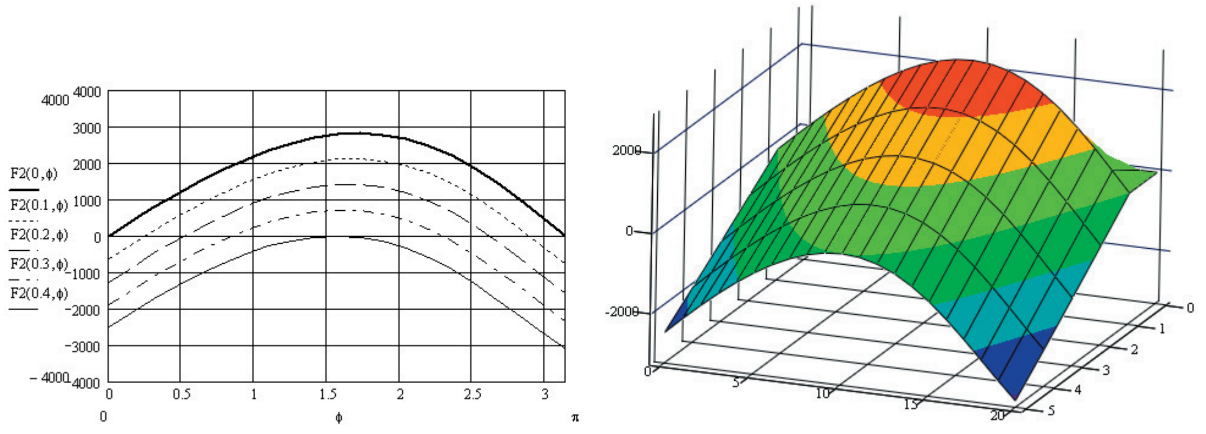
$$F_y = \frac{10^3 \cdot F_n \cdot V_{np} \cdot \left(\frac{R \cdot \sin\varphi - e}{l}\right)}{V_0 - F_n \cdot \left(R \cdot (1 - \cos\varphi) - \left[l - \sqrt{l^2 - (R \cdot \sin\varphi - e)^2}\right] - \frac{h_n}{2\pi} \cdot \varphi\right)}. \qquad (8)$$

Using the formula (8) we can define with the help of PC in the MathCAD environment the value of eccentricity e of the crank shaft axis relatively to the axis of the piston at which the maximum in the injection tact of transverse force F_y will be the least. The calculations are done with the following operation factors: F_n = 0,64 dm^2; V_{np} = 26 dm^3; R= 0,4 dm; V_0 = 1,3 dm^3; that corresponds to the initial pressure 2 MPa; l = 2 dm; h_n=0,8 dm; φ = 0…π; e = 0; 0,1; 0,2; 0,3; 0,4 dm.

The results of our calculations are given in graphs. The graphs of dependence of the transverse force F_y , that affects the slider of piston group of the φ angle of the crank shaft turn, are shown in the figure a, b. Each of the graphs corresponds to a certain displacement value e.

These graphs indicate firstly that the value of transverse force F_y during the tact of injection changes smoothly and passes through a maximum. Secondly, the disposition of this maximum doesn't correspond to the angle φ = 0,5π, when the eccentricity of crank is directed vertically and shifted toward the corner φ > 0,5π. This can be explained by the fact that the disposition of maximum F_y is affected not only by α angle of inclination to the horizontal rod but also it is affected by the level of the solution pressure p_φ that, according to the figure 4 [4], reaches the largest value at approximately φ =2,7 rad. It is interesting that the disposition of this maximum toward the turn of the crank φ with the increase of the value e shifts to the left and the negative value of transverse force in the end of injection tact exceeds this value at the beginning of the tact. The larger value of displacement e is, the bigger the extent of this transcending is. Thirdly, the value Fy remains positive during the whole tact of injection (φ = 0…π) in the absence of offset crank shaft axis from the axis of the piston (e =0). That means that the transverse force Fy is directed only in one direction during the entire cycle. When there is displacement e at the beginning and at the end of injection tact, cross forces of negative value appear. This indicates the changes of the transverse force F_y action direction on 180^0.

The graph of dependence of transverse force on the value of displacement e is made according to the maximal and minimal values of transverse forces taken from fig. 2. It is depicted in the fig. 3. This graph shows that with the increasing of displacement e, the positive value of transverse force F_y is reduced directly proportional to e. And vice versa, its negative value increases from zero at e = 0 and till the maximum at e = 0,4 dm.



а)

б)

Fig. 2. The curves of cross change efforts F_y during the cycle with different values of eccentricity e, dm; a - two-dimensional graph of dependence; b — three-dimensional graph of dependence with the usage of two-dimensional matrix type: M_{ij} = f (e_i , φ_j), where i = 1…5, j = 0…20, e_i = (i-1)/10, φ_j = π j/ 20

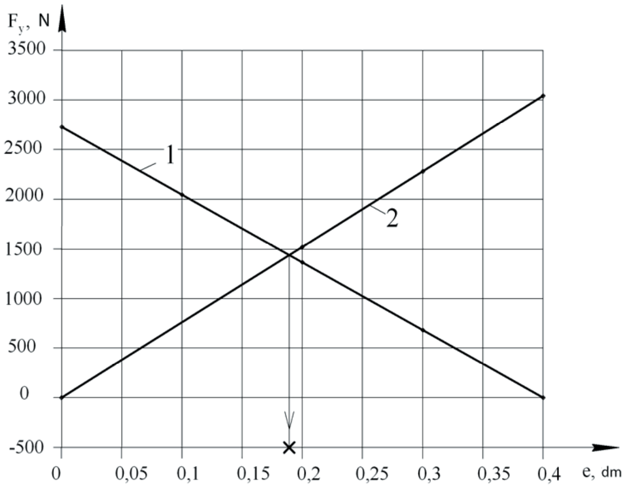


Fig.3. The graph of dependence of maximal positive (1) and negative (2) values of transverse forces F_y from the displacement e

When the value of displacement equals 0,4 dm, the transverse forces are also directed in one direction as it is at e = 0. The difference is in the fact that these forces are negative, that is they are directed in the opposite direction. The best variant will be when the absolute value of transverse force F_y is the least independent on the direction of this force's action.

As it is shown in the fig. 3, such force is in the cross point of curves which describe the dependence of e on positive and negative values of force F_y. This point corresponds to the displacement value e, which equals 0,18 dm, that is 45% of the crank radius R= 0,4 dm. So with the displacement of crank axis relatively to the piston axis on 45% of crank radius transverse forces that affect the piston slider group during the work of the pump with the combined pressure compensator will be the least at the absolute value and will be directed to the different sides during the injection tact with the same maximum value.

6. Conclusion

So the optimal displacement of e is 45% of the crank displacement radius. With this displacement the total value of transverse force is divided in two equal parts, which are directed into opposite sides. As a result, the transverse forse F_y is reduced twice, that promotes the reduction of wear and tear and increases the resource work of rubbing details of piston group and of single-cylinder pump.

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Abstract

As there is not any area in petroleum industry where the pumps wouldn't be used, the further improvement of their technical and economic indicators remains to be the main problem of petroleum industry.

The axis of crank shaft, the construction of which is represented by us, is shifted down relatively to axis of piston on purpose of transverse force's reduction which affects the piston's slider during the work of pump. The quantity of deflection e will be optimal when the transverse force Fy, which is represented in fig. 1, is a minimum share of maximum axial working force Fxmax.

This paper introduces using the formulas for defining value of eccentricity e. The results of calculations are given in graphs.These graphs indicate firstly that the value of transverse force Fy during the tact of injection changes smoothly and passes through a maximum, secondly, the disposition of this maximum doesn't correspond to the angle $\varphi = 0{,}5\pi$, *when the eccentricity of crank directed vertically and shifted toward the corner* $\varphi > 0{,}5\pi$.

So the optimal displacement e is 45% of the crank displacement radius.Our research shows that with the displacement of crank axis relatively to the piston axis on 45% of crank radius transverse forces will be the least at the absolute value and will be directed to the different sides during the injection tact with the same maximum value

Keywords*: crank, pump, force*