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KINEMATIC STUDY OF A FOUR-LINK MECHANISM FOR THE PURPOSE OF ITS USE IN THE DESIGN OF NEW MACHINES

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Annotation. This article presents a kinematic study of a four-link mechanism intended for application in the design of new machines. During the design process, especially in the automation of machines and mechanisms, it is essential to determine kinematic parameters. These parameters are obtained through analytical calculations and by developing computer-based calculation programs. The paper provides an example of calculating a specific mechanism with a detailed analysis of its characteristics. Based on this example, similar problems for other related mechanisms can be effectively solved.

Keywords: mechanism, kinematics, automation, velocity, acceleration, calculation, program, parameter, design, model

Annotatsiya. Ushbu maqolada to‘rt zvenoli mexanizmning kinematik tadqiqi va uni yangi mashinalarni loyihalashda qo‘llash masalalari ko‘rib chiqiladi. Mashina va mexanizmlarni loyihalashda, ayniqsa ularni avtomatlashtirish jarayonida, kinematik parametrlarni aniq bilish muhim ahamiyatga ega. Ushbu parametrlar maxsus hisob-kitoblar hamda EHM uchun tuzilgan dasturlar yordamida aniqlanadi. Maqolada aniq bir mexanizm misolida kinematik hisoblash bosqichlari keltiriladi. Ushbu uslub asosida boshqa shunga o‘xshash mexanizmlarning masalalarini ham yechish mumkin.

Tayanch so'zlar: mexanizm, kinematika, avtomatlashtirish, tezlik, tezlanish, hisob, dastur, parametr, loyiha, model

Аннотация. В статье рассматривается кинематическое исследование четырехзвенного механизма с целью его применения при проектировании новых машин. При проектировании, особенно при автоматизации машин и механизмов, необходимо знать кинематические параметры системы. Эти параметры определяются расчетным путем и с использованием программ для вычисления на ЭВМ. В работе приводится пример расчета конкретного механизма с подробным анализом его характеристик. На основе данного примера возможно решение задач для других аналогичных механизмов.

Ключевые слова: механизм, кинематика, автоматизация, скорость, ускорение, расчет, программа, параметр, проектирование, модель

When designing machines and mechanisms, especially when automating them, it's essential to know the kinematic parameters, which are determined by calculations and computer programs. To this end, we provide an example calculation for a specific mechanism, which can be used to solve other similar mechanisms.

The task is to construct plans for the speeds and accelerations of a compressor crank-slider mechanism (Fig. 1, a). Find the speed and acceleration of point *C*, the angular velocity and angular acceleration of connecting rod *BC*, and determine the length of the radius of curvature ρ_D of the trajectory of point D. Given: $\varphi_1 = 45^o$, $l_{AB} = 0{,}06\,m$, $l_{BC} = 0{,}18\,m$, $l_{BD} = 0{,}09\,m$, the angular velocity of crank *AB* is constant and equal to $\omega_1 = 100\ \text{c}^{-1}$ [1, 2]

Solution. We conduct a structural analysis and determine the class of the given mechanism. The number of links is k = 4, the degree of freedom of the mechanism is n = 3, the number of kinematic pairs of class *V* is P_5 = 4, and the degree of freedom of the mechanism is $W = 3n - 2P_5 = 3 \cdot 3 - 2 \cdot 4 = 1$. The mechanism is formed by connecting a second-class, second-type group consisting of links 2 and 3 to the drive link AB and post 4 [3, 4].

We construct a plan of the mechanism's position (Fig. 1, b). We set the length of segment *AB* = 30 mm and calculate the scale of the mechanism diagram:

$$\mu_l = \frac{l_{AB}}{AB} = \frac{0{,}06}{30} = 0{,}002\ \frac{m}{mm},$$

and from it we find the lengths of the segments (*BC*) and (*BD*):

$$(BC) = \frac{l_{BC}}{\mu_l} = \frac{0{,}18}{0{,}002} = 90\ mm, \quad (BD) = \frac{l_{BD}}{\mu_l} = \frac{0{,}09}{0{,}002} = 45\ mm,$$

Based on the obtained dimensions and the given angle φ_1 in Fig. 1.b, we construct a plan of the mechanism's position.

We construct a plan of the velocities for groups 2 and 3. We construct the plan using the following two vector equations [5, 6]:

$$v_C = v_B + v_{BC}, \qquad v_C = v_{C_4} + v_{CC_4},$$

where $v_B -$ is the velocity of point *B*, equal in magnitude to $v_B = \omega_1 l_{AB} = 100 \cdot 0{,}06 = 6\ \frac{m}{s}$ and directed perpendicular to line *AB* in the direction corresponding to the direction of the angular velocity of link *AB*; $v_{BC} -$ is the velocity of point *C* during rotation of link *BC* about hinge *B*, equal in magnitude to $v_{CB} = \omega_2 l_{BC}$ $(\omega_2) -$ is the angular velocity of link *BC*, which is still unknown to us) and directed perpendicular to line *BC*; $v_{C_4} -$ is the velocity of point C_4 of rack 4, coinciding with point *C* (it is equal to zero, since link 4 is motionless); $v_{CC_4} -$ is the relative velocity of point *C* in its motion relative to point C_4 (its modulus is unknown, and it is directed along line A_x) [7, 8].

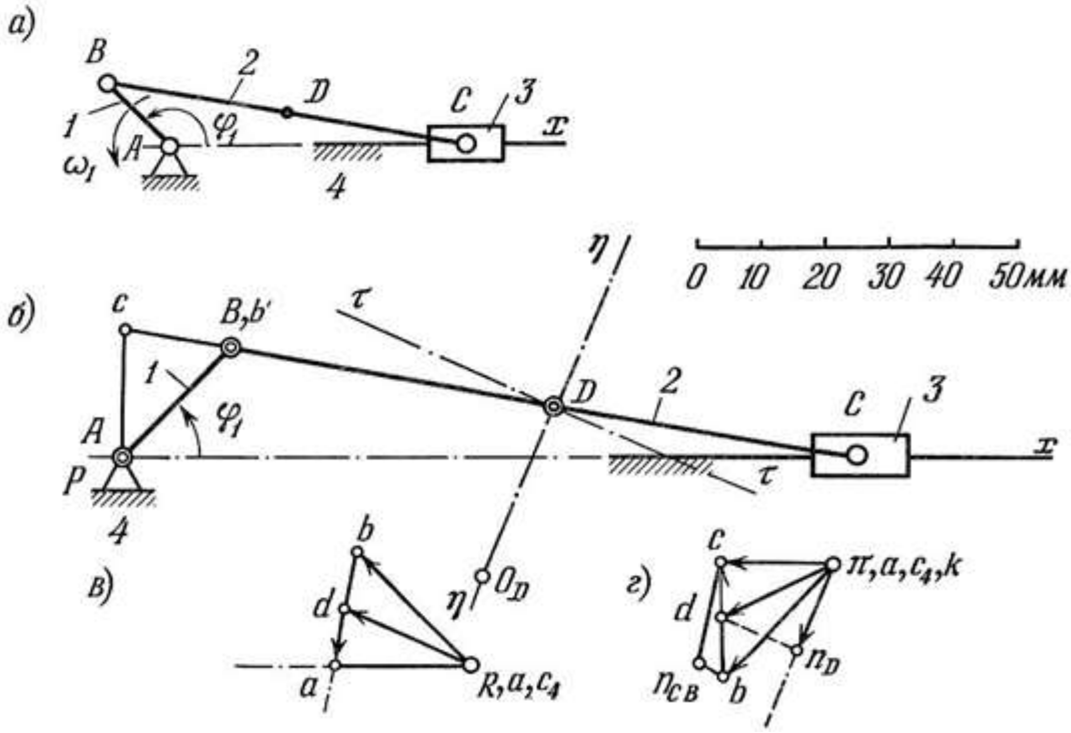

Figure 1. Kinematic analysis of the compressor slider-crank mechanism: a) mechanism diagram, b) mechanism position plan, c) speed plan, d) acceleration plan.

We construct the velocity plan in the following sequence (Fig. 1, b). We construct the solution to the first vector equation indicated above (6): from the pole p, we lay off a segment (*pb*), representing the velocity of point *B*, perpendicular to line *AB* and in accordance with the direction of rotation of link *AB*, and we choose the length of the segment (*pb*) equal to (*AB*) = 30 *mm*, i.e., we construct the plan in the scale of the crank; from point b, we draw the direction of velocity v_{CB} – a line perpendicular to *BC* [9,10]. We proceed to constructing the solution of the second vector equation indicated above: from point *p*, we would need to plot the velocity v_{C_4}, but it is equal to zero, so we coincide point c_4 with point p; from point c_4, or, equivalently, *p*, we draw the direction of the velocity v_{CC_4} – a line directed by *Ax* - until it intersects with a line drawn perpendicular to *BC*, and obtain point c – the and of the velocity vector of point *C*. We place point a at the pole of the plan and thus complete the construction of the velocity plan for the entire mechanism. We find the velocity of point *D* using the similarity rule: the end of this velocity vector must lie on line (*bc*) and divide segment *BC*, *i.e*.

$$(bd) = \frac{(BD)}{(BC)}(bc) = 0{,}5(bc)$$

We calculate the scale of the speed plan:

$$\mu_v = \frac{v_B}{pb} = \frac{\omega_1 (AB)\mu_l}{(pb)} = \omega_1 \mu_l \ \ \frac{m/s}{mm}$$

The scale of the speed analog plan will be [11]

$$\mu_{\varphi v} = \frac{\mu_v}{\omega_1} = \mu_l \ \ \frac{m/s}{mm}$$

The velocity v_C of point *C* is equal to

$$v_C = (pc)\mu_v = 20 \cdot 100 \cdot 0{,}002 = 4{,}0 \ \ m/s$$

The angular velocity ω_2 of link *BC* is equal to [12]

$$\omega_2 = \frac{(bc)\mu_v}{(BC)\mu_l} = \frac{(bc)\omega_1\mu_l}{(BC)\mu_l} = \frac{18 \cdot 100}{90} = 20 \ \ t/s$$

In figure 1b, a rotated velocity diagram is plotted directly on the mechanism diagram. In this diagram, pole p is aligned with point *A*. The direction of the velocity vector at point *B* coincides with the direction of *AB*, the direction of the velocity v_{CB} is an extension of line *BC*, and the direction of the velocity at point *C* is perpendicular to line A_x.

We construct an acceleration plan for group 2, 3. This plan is constructed using the following two vector equations [13]:

$$a_C = a_B + a_{CB} = a_B + a_{CB}^n + a_{CB}^t, \qquad a_C = a_{C_4} + a_{CC_4}^n + a_{CC_4}^t$$

where a_B – is the normal acceleration (also total) of point *B*, equal in magnitude

$$a_B = \omega_1^2 \cdot l_{AB} = 100^2 \cdot 0{,}06 = 600 \ \ m/s$$

and directed parallel to line *AB* from point *B* to point *A*; a_{CB}^{n} – is the normal acceleration of point *C* in the rotational motion of link *BC* relative to point *B*, equal in magnitude

$$a_{CB}^{n} = \frac{v_{CB}^{2}}{l_{BC}}$$

and directed parallel to line *BC* from point *C* to point *B*; a_{CB}^{t} – tangential acceleration of point *C* in the same motion of link *BC*, equal in modulus to $a_{CB}^{t} = \varepsilon_2 \cdot l_{BC}$ and directed perpendicular to line *BC*; a_{C_4} – acceleration of point C_4 (point of link 4; it is equal to zero, since link 4 is motionless); $a_{CC_4}^{k}$ – Coriolis acceleration of point *C* in its motion relative to point C_4, equal to zero, since link 4 is motionless; $a_{CC_4}^{r}$ – relative (relative) acceleration of point *C* in its motion relative to point C_4, it is directed along line A_x.

We construct the acceleration plan in the following sequence (Fig. 1, d). We construct the solution to the first vector equation indicated above by plotting a segment (πb) from the pole of the plan π, representing the acceleration a_B, parallel to the line *AB*. We choose the length (πb) equal to (*AB*) = 30 *mm*, *i.e.*, we construct the plan at the crank scale, while the scales of the acceleration plans and their analogs will be equal to

$$\mu_a = \frac{a_B}{\pi b} = \frac{\omega_1^2 (AB)\mu_l}{(\pi b)} = \omega_1^2 \mu_l = 100^2 \cdot 0{,}002 = 20\ \frac{m/s^2}{mm}$$

$$\mu_{\varphi a} = \frac{\mu_a}{\omega_1^2} = \mu_l = 0{,}002\ \frac{m}{mm}$$

From point *b*, we plot a segment bn_{CB} representing the acceleration a_{CB}^{n}. The length of the segment (bn_{CB}) is calculated using the formula [14]

$$bn_{CB} = \frac{a_{CB}^{n}}{\mu_a} = \frac{v_{CB}^{2}}{l_{BC} \cdot \mu_a} = \frac{(bc)^2 {\mu_v}^2}{(BC)\mu_l \cdot \mu_a} = \frac{(bc)^2 \omega_1^2 \mu_l^2}{(BC)\mu_l \cdot \mu_a} = \frac{(bc)^2}{(BC)} = \frac{(18)^2}{90} = 3{,}6\ mm$$

Through point n_{CB} we draw the direction of acceleration a_{CB}^{t} –, a line perpendicular to line *BC*. We proceed to constructing the solution of the second vector equation indicated above. To do this, we plot the acceleration vector a_{c_4} from the pole of the plane π, but it is equal to zero, therefore point c_4 coincides with point π. The end of the acceleration vector $a^k_{CC_4}$ – point *k*, also coincides with this point (the acceleration $a^k_{CC_4}$ is equal to zero). From point *k*, or, what is the same, from point π, we draw the directions of acceleration with a line drawn perpendicular to *BC*, yielding point c, the end of the acceleration vector of point *C*.

Connecting points *c* and *b* yields the total acceleration vector of point *C* as link *BC* rotates relative to point *B*, i.e., a_{CB}. We place point a at point π. This completes the construction of the mechanism's acceleration diagram. We find the endpoint of the acceleration vector of point *D* using the similarity rule [15]:

$$(bd) = \frac{(BD)}{(BC)}(bc) = 0{,}5(bc)$$

Connecting point *d* with the pole of the plane π, we obtain a segment (πd), representing the acceleration of point *D*.

The magnitude of the acceleration of point *C* is determined as follows:

$$a_C = (\pi \text{c}) \cdot \mu_a = 17{,}8 \cdot 20 = 356 \ \text{м/с}^2$$

and the magnitude of the angular acceleration of link *BC*

$$\varepsilon_2 = \frac{a^t_{CB}}{l_{BC}} = \frac{(n_{CB}c)\mu_a}{(BC)\mu_l} = \frac{(n_{CB}c)\omega_1^2 \cdot \mu_l}{(BC)\mu_l} = \frac{(n_{CB}c)^2\omega_1^2}{(BC)} = \frac{18 \cdot 100^2}{90} = 2000 \ 1/c^2$$

We find the radius of curvature of the trajectory of point *D*. Through point *D* (Fig. 1, *b*) we draw a line $\tau\tau$, parallel to the segment (*pd*) on the velocity plane (Fig. 1, *c*) - this will be the direction of the tangent to the trajectory of point *D*. Line ($\eta\eta$), drawn perpendicular to line (ηη), is the normal to the same trajectory. The center of curvature O_D of the trajectory of point *D* is located on it. We project the acceleration vectors of point *D*, segment (πd) (Fig. 1, *d*), onto the direction of the normal to the trajectory of point *D*. We obtain segment (πn_D), corresponding to the normal acceleration a^n_D of point *D* from the formula

$$a_D^n = \frac{v_D^2}{\rho_D}$$

we get that the desired radius of curvature will be equal to

$$\rho_D = \frac{v_D^2}{a_D^n} = \frac{(\rho d)^2 \mu_a^2}{(\pi n_D)\mu_a} = \frac{(\rho d)^2 \omega_1^2 \mu_l^2}{(\pi n_D)\omega_1^2 \mu_l} = \frac{(\rho d)^2}{(\pi n_D)}\mu_l = \frac{22^2}{16} \cdot 0{,}002 = 0{,}0605\, m$$

The presented method of kinematic calculation of the mechanism allows for more accurate design and can be useful for students and masters, as well as scientific researchers.

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