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# Methods Of Kinematic Study of Flat Base Mechanisms

**[1]Shodiyev Ziyodullo Ochilovich [2]Dustkarayev Nortayloq Abdug'aniyevich**
**[3]Shodiyev Sadir Ne'matovich [4]Shodiyev Ne'matjon Sadirovich,**
[1]Bukhara branch of Tashkent Institute of Irrigation and Agriculture Mechanization Engineers
[2]Bukhara branch of Tashkent Institute of Irrigation and Agriculture Mechanization Engineers
[3]Bukhara branch of Tashkent Institute of Irrigation and Agriculture Mechanization Engineers
[4]Bukhara branch of Tashkent Institute of Irrigation and Agriculture Mechanization Engineers

**Abstract:** The article covers the method for determining linear velocities and accelerations of individual points and angular velocities and accelerations of links for mechanisms with lower kinematic couples, which are widely used in many industry branches due to reliability, technological effectiveness and ability to transmit great loads.

**Keywords:** linear velocities, angular velocities, kinematic problems, kinematic studies, motion, driving link, velocity plan, acceleration plan, lever mechanism.

## Introduction

Any science systematizes the objects of research, and applied science, in addition to studying the object, develops methods for its design, modernization and improvement to meet the positions of an increasingly complex mechanical design task. Applied mechanics in general, and engineering science in particular, studies machines and mechanisms as objects, the fundamental and constructive variety of which is tens of thousands of items. A simple study of their properties requires a significant amount of time, which is practically unrealizable in the vocational education system. Therefore, in applied mechanics, a classification of objects has been developed, which is based on their division according to functional, structural or other characteristics. And, choosing a typical object from a specific family (class), investigate its properties, and also determine the methods of creating the entire family (class), this saves time and allows you to organize an effective educational process for training specialists in the field of mechanical engineering [3, 4, 5,6 ].

## Materials And Methods

As noted above, flat lever mechanisms containing lower kinematic pairs are widely used in many industries due to their reliability, manufacturability and ability to transfer large forces [3, 4, 5, 6]. Since the mechanism is designed to transform motion, it is the regularity of such a transformation that is the subject of the kinematic problem.

In the kinematic study of flat lever mechanisms, the following particular problems are solved:

1) determination of the positions of the links of the mechanism and individual trajectories of its points to find the space occupied by the operating mechanism;

2) determination of linear velocities (accelerations) of points of the mechanism and angular velocities (accelerations) of its links.

When solving these problems, it is necessary to know the kinematic diagram of the mechanism, the nature of the connections and the kinematic dimensions of its links, as well as the law of motion of the driving link. The input motion of the leading link is considered to be known and simple. This is due to the fact that all engines are mass-produced, have simple output movements - rotary or translational, and the engine power overlaps the power of the production process performed by the machine [3, 4].

Based on the results of the kinematic analysis, the correspondence of the displacements, speeds and accelerations of the links of the mechanism to the specified values is established. The solutions to the kinematic problem are the initial ones for the subsequent dynamic and kinetostatic calculations. The solution of the kinematic problem provides for the idealization of the object and general assumptions. Namely, the calculations do not take into account the forces causing the movement, as well as the friction forces, the

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masses of the links, while all the links are made exactly and do not have deformations (i.e., absolutely rigid), in there are no gaps in movable joints [6].

A kinematic study can be carried out by an analytical or graphical method, the latter is distinguished by its clarity and ease of implementation [5,6,19,16,20].

Determination of displacements, velocities and accelerations in mechanisms with lower pairs begins to be carried out from the leading link to the slave, that is, the order of kinematic research corresponds to the formula for the structure of the mechanism.

In addition to the problem of kinematic analysis, of particular interest is the problem of kinematic synthesis or synthesis of a mechanism diagram according to a given law of transformation of motion "input - output". The solution of such a problem is rather difficult and feasible on a computer by means of optimization of multi-parameter functions with the involvement of specialized software products [5,6,19].

## Results And Discussions.

When solving problems of this type, the angular velocity $\omega_1$ of the driving link 1 - the crank, the lengths of the links and the coordinates of the fixed points are known.

The sequence of solving the problem:

1. A plan of the mechanism is constructed (Fig. 1) in the selected length scale:

$$\mu_l = \frac{L_{OA}}{OA}, \left[\frac{m}{mm}\right]$$

where, $L_{OA}$ - crank length, m; $OA$ - length of the segment depicting the crank on the plan of the mechanism, mm.

To construct the plan of the mechanism, the remaining lengths of the links and the coordinates of the fixed points of the hinged four-link link (Fig. 1) are converted by the scale of lengths into segments $\mu_l$ [18, 19, 20]:

$$AB = \frac{L_{AB}}{\mu_l}, mm;$$

$$BC = \frac{L_{BC}}{\mu_l}, mm;$$

$$OC = \frac{L_{OC}}{\mu_l}, mm$$

Vector equations of linear velocities of individual points belonging to the links of the mechanism are compiled.

Vector equation for link 2 (connecting rod):

$$v_B = v_A + v_{BA}$$

where, $v_A = v_{AO}$ – speed of point A, which is equal to the speed of point A relative to the axis of rotation of the crank of point O; $v_{BA}$ – vector of the relative speed of point B of the connecting rod relative to A has a direction perpendicular to the segment AB on the plan of the mechanism.

Vector equation for link 3 (rocker arm):

$$v_B = v_C + v_{BC}.$$

Since point C (the axis of rotation of the rocker arm 3) is stationary, its speed is zero $v_C = 0$, and the vector of the relative speed of point B relative to C $v_{BC}$ has a direction perpendicular to the BC segment on the plan of the mechanism.

A plan of the speeds of the mechanism is being built - this is nothing but a graphic representation on the drawing of vector equations (1) and (2) in any scale [18, 19, 20].

Speed plan of the mechanism and its properties.

It is desirable to build a plan of speeds next to the plan of the mechanism (Fig. 1. b). The speed of point A of the crank is pre-calculated:

$$v_A = \omega_1 \cdot L_{OA}, \left[\frac{m}{s}\right].$$

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Then the scale of the plan of speeds is selected $\mu_v$ according to the ratio:

$$\mu_v = \frac{v_A}{Pa}, \left[\frac{m}{s \cdot mm}\right]$$

where $v_A$ is the speed of point A, $\frac{m}{s}$; $Pa$ - length of the segment representing the speed $v_A$ in the future plan of speeds, chosen of an arbitrary length in mm. When choosing, it is advisable to adhere to the conditions: firstly, the plan of speeds should be placed in the designated place of the drawing, and secondly, the numerical value of the scale $\mu_v$ should be convenient for calculations ( $\mu_v$ should be a round number).

After that, you can start building a plan for the speeds of the mechanism. It should be carried out in the sequence corresponding to the writing of the vector equations (1) and (2).

First, it is carried out from a point randomly selected near the plan of the mechanism $P$ (poles of the plan of velocities) vector of speed $v_A$, which is perpendicular to the segment OA on the plan of the mechanism and has a length $Pa$, chosen by us when determining the scale of the plan of speeds $\mu_v$. Then, through point a, a line is drawn perpendicular to the segment AB of the plan of the mechanism, and through the pole $P$ - a line perpendicular to the segment BC. The intersection of these lines gives point b. In accordance with the vector equations (1) and (2), the directions (arrows) of the vectors $v_A$ and $v_{BA}$ are plotted on the constructed plan [18,19,20].

We determine the speed of point K, which belongs to the connecting rod. For it, you can write down the vector equations of velocities [18,19,20]:

$$\begin{cases} v_K = v_A + v_{KA} \\ v_K = v_B + v_{KB} \end{cases}$$

where is the velocity vector $v_{KA}$ is perpendicular to the KA segment on the plan of the mechanism, and the vector $v_{KB}$ - to the KB segment.

By constructing these vector equations, we obtain point k on the plan of velocities. In this case, from point a of the plan of speeds draw a line perpendicular to the segment AK, and through point b of the plan of speeds - a line perpendicular to the segment VK of the plan of the mechanism. The magnitude of the speed of the point K can be calculated by the formula

$$v_K = (Pk)\mu_v$$

where $Pk$ is the length of the corresponding vector on the plan of velocities [3,4,5,18,19,20].

You can see that the triangles on the plan of speeds and plan of the mechanism are similar:

$$\Delta abk \approx \Delta ABK$$

since their sides are mutually perpendicular. This property can be used to determine the speed of any other point belonging to any link in the mechanism. Hence follows the similarity theorem: the segments of the relative speeds on the plan of speeds form a figure similar to the figure of the corresponding link on the plan of the mechanism. The sides of the figures are mutually perpendicular [3,4,5,19,20].

The angular speeds of the connecting rod 2 and the rocker arm 3 are calculated by the formulas:

$$\omega_2 = \frac{v_{AB}}{L_{AB}} = \frac{(ab)\mu_v}{L_{AB}}, \frac{1}{s}$$

$$\omega_3 = \frac{v_{BC}}{L_{BC}} = \frac{(bc)\mu_v}{L_{BC}}, \frac{1}{s}$$

The directions of angular velocities are determined by the directions of vectors $v_{AB}$ and $v_{BC}$. For this, the vector $v_{AB}$ is conventionally transferred to point B of the mechanism plan. There it will rotate the connecting rod 2 relative to point A, the angular velocity of the connecting rod $\omega_2$ will be directed in that direction.

We do the same with speed $v_{AB}$. In which direction the rocker arm will rotate relative to point C, there the angular velocity will be directed $\omega_3$.

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**Mechanism acceleration plan and its properties.**

The sequence of building a plan of acceleration of the linkage mechanism is similar to building a plan of speeds. Let's consider it by the example of a four-link hinge mechanism (Fig. 1.c). Let's take the angular speed of the crank constant ($\omega_1 = const$ which is the most common and rational type of movement in real mechanisms) [3,4,5,18,19,20].

Vector equation of accelerations for link 1 (crank):

$$a_A = a_{OA}^n + a_{OA}^\tau$$

where the normal component of the acceleration of point A relative to O is calculated by the formula $a_{OA}^n = \omega_1^2 \cdot L_{OA}$.

Vector $a_{OA}^n$ is parallel to the AO segment on the plan of the mechanism. The tangential component of acceleration $a_{OA}^\tau$ is calculated by the formula $a_{OA}^\tau = \varepsilon_1 \cdot L_{OA}$.

In our case, the angular acceleration of the crank $\varepsilon_1 = 0$, then $a_{OA}^\tau = 0$.

The vector equation of accelerations for link 2 (connecting rod):

$$a_B = a_A + a_{AB}^n + a_{AB}^\tau$$

where the normal component of the acceleration of point B relative to point A is calculated by the formula:

$$a_{AB}^n = \omega_2^2 \cdot L_{AB}.$$

The vector $a_{AB}^n$ is parallel to the segment AB and is directed from B to A, and the tangential component $a_{AB}^\tau$ perpendicular to AB [19,20].

The vector equation of accelerations for link 3 (rocker arm):

$$a_B = a_c + a_{BC}^n + a_{BC}^\tau$$

where is the acceleration of point C $a_c$; the normal component of the acceleration of point B relative to point C is calculated by the formula $a_{BC}^n = \omega_3^2 \cdot L_{BC}$.

The vector $a_{BC}^n$ is directed parallel to the segment BC of the plan of the mechanism from B to C, and vector $a_{BC}^\tau$ is perpendicular to BC.

We select the scale of the acceleration plan: $\mu_a = \frac{a_{OA}^n}{Pa}, \left[\frac{m}{s^2 \cdot mm}\right]$ where $Pa$ is the length of the segment representing the acceleration $a_{OA}^n$ on the acceleration plan. Its length is chosen arbitrarily from the calculation so that the acceleration plan is located in the designated place of the drawing and the numerical value $\mu_a$ was convenient for calculations ($\mu_a$ should be a round number) [3,4,5,18,19,20].

Then acceleration $a_{BA}^n$ will be represented on the acceleration plan by a vector with length $a'n_2 = \frac{a_{AB}^n}{\mu_a}$ mm, and acceleration $a_{BC}^n$ - by a vector of length $P_a n_3 = \frac{a_{BC}^n}{\mu_a}$ mm.

Then an acceleration plan is constructed (Fig. 1.c) using the compiled vector acceleration equations. An acceleration vector is drawn from an arbitrarily chosen pole $Pa$ parallel to the segment OA of the mechanism plan $a_{OA}^n$, the length of which $Pa$ was chosen arbitrarily when calculating the scale $\mu_a$. From the end of this vector (point a), an acceleration vector is drawn $a_{BA}^n$ with length $a_{n2}$, which should be parallel to the segment AB of the mechanism plan and directed from point B to point A. Perpendicular to it through a point $n_2$ we draw a straight line. Then the acceleration vector is drawn from the pole $Pa$ $a_{BC}^n$ length $Pn_3$. A straight line is drawn perpendicular to it through point $n_3$ until it intersects with a straight line drawn through point n2 perpendicular to the segment AB. The point of intersection is denoted by the letter b

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', which, being connected to the pole of $Pa$, forms a segment $Pab$, representing the vector of the total acceleration of point B [5,6,16].

Using the acceleration plan, accelerations can be calculated:

$a_B = Pb \cdot \mu_a,$

$a_{AB} = ab \cdot \mu_a$

Let's write down:

$$a_{BC} = ab \cdot \mu_a = L_{AB} \cdot \sqrt{\omega_2^4 + \varepsilon_2^2}$$

where $\omega_2$ and $\varepsilon_2$ are the angular velocity and acceleration of the connecting rod:

$$\frac{a'b'}{AB} = \frac{\mu_L}{\mu_a}\sqrt{\omega_2^4 + \varepsilon_2^2}$$

where $\omega_2$ and $\varepsilon_2$ do not depend on the choice (location) of the $Pa$ pole of the acceleration plan, and the ratio of the scales is constant ($\frac{\mu_L}{\mu_a} = const$) for the given acceleration plan. Therefore, for any point (for example, K belonging to the connecting rod), you can write the proportions:

$$\frac{a'b'}{AB} = \frac{a'k'}{AK} = \frac{b'k'}{BK}.$$

Hence the similarity theorem is formulated: the segments of the total relative accelerations on the plane of accelerations form a figure similar to the corresponding figure of the link on the plan of the mechanism [5,6,16,17,18].

The magnitude of the acceleration of point K can be calculated by the formula:

$a_k = Pk \cdot \mu_a.$

Angular acceleration of the connecting rod links $\varepsilon_2 = \frac{a_{AB}^{\tau}}{L_{AB}}, \left[\frac{1}{s}\right]$, direction $\varepsilon_2$ is determined by $a_{BA}^{\tau}$; angular acceleration of the rocker arm links $\varepsilon_3 = \frac{a_{BC}^{\tau}}{L_{BC}}, \left[\frac{1}{s}\right]$, direction $\varepsilon_3$ - along $a_{BC}^{\tau}$.

As $\omega_2$ and $\varepsilon_2$ are directed in opposite directions, the rotation of the connecting rod is slowed down. We use a velocity plan and an acceleration plan to determine the radius of curvature of a point's path.

The radius of curvature of the trajectory of a point (for example, point K) can be calculated by the formula:

$$Pk = \frac{v_K^2}{a_K^n} = \frac{(P_v k)^2 \mu_v^2}{mk \cdot \mu_a}$$

where $a_K^n$ is the normal component of the acceleration of point K.

To determine the magnitude (and direction) $a_K^n$ the full acceleration vector $a_K$ should be decomposed on the acceleration plan into normal and tangential components, and $a_K^n$ is perpendicular to the velocity vector $v_K$, $a_K^{\tau}$ is parallel to the latter. For this, first, a straight line is drawn through the pole of the acceleration plan $Pa$, parallel to the velocity vector of point K, and through the point $k$ - perpendicular to this straight line; point m is obtained at their intersection [16,17,19].

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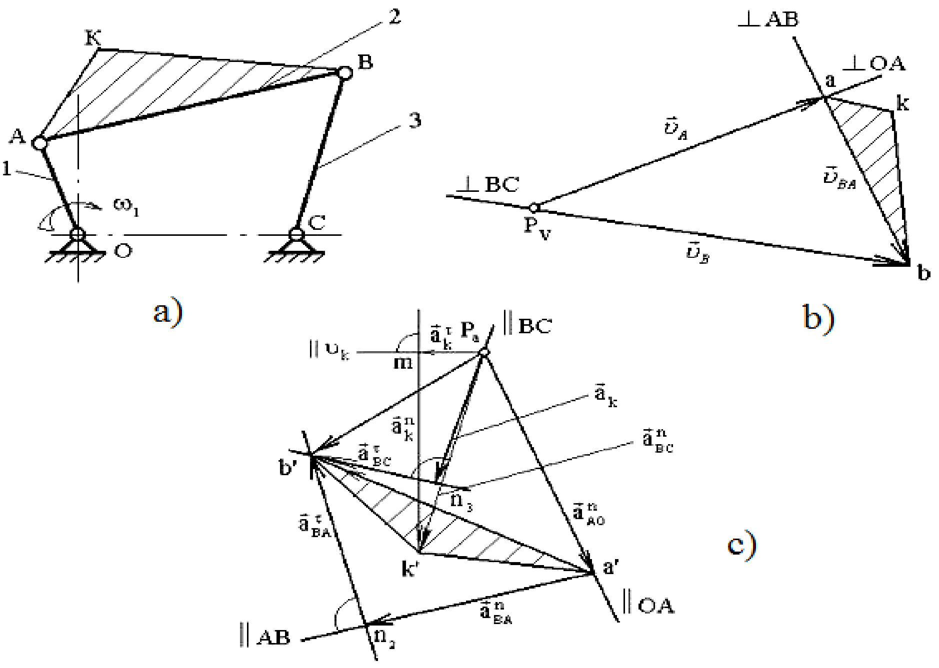


**Fig. 1. a) Type of mechanism; b) plan of speeds; c) plan of accelerations**

## Conclusions

The main purpose of the mechanism is to perform the required movements. These movements can be described by means of its kinematic characteristics. These include the coordinates of points and links, their trajectories, speeds and accelerations. The kinematic characteristics also include those characteristics that do not depend on the law of motion of the initial links, are determined only by the structure of the mechanism and the size of its links, and in the general case depend on the generalized coordinates. These are position functions, kinematic transfer functions of speed and acceleration. The plan method is one of the most illustrative. Linear velocities and accelerations of individual points and angular velocities and accelerations of links are subject to determination. In this case, the vector equations for the velocities and accelerations of the points of the links performing a complex motion are preliminarily compiled. The main purpose of the mechanism is to fulfill the required ones.

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