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KINETOSTATIC ANALYSIS OF A FIVE-LINK FLAT MECHANISM

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Abstract: The article considers the first problem of dynamics. With a known law of motion of a five-link flat mechanism, which also includes a higher kinematic pair, unknown forces are determined. The reaction forces in kinematic pairs and the balancing force applied to the input link of the mechanism are determined by the graphoanalytical method.

Keywords: *kinetostatics, degree of freedom, reaction forces, Assur group, kinematic pair.*

Introduction.

Kinetostatic analysis of a mechanical system refers to the first problem of dynamics. In this problem, unknown forces are determined for a known law of motion of a mechanical system. Kinetostatic analysis of flat lever mechanisms has been considered in sufficient detail at present. However, it should be noted that flat mechanisms, which also include higher kinematic pairs, have not been studied enough.

For example, in [1] flat tensegrity mechanisms with three linear springs are analyzed in detail. Kinetostatic equations are derived and solved under several load conditions and geometric conditions. The paper [2] is devoted to the method of numerical solution of a 5-link vehicle suspension mechanism. The multidimensional Newton method and regularization are used as the mathematical apparatus. The paper [3] studies a flat tensegrity manipulator consisting of two X-mechanisms connected in series. Unlike the classical 2-R-linkage, the proposed architecture does not contain elements subject to bending. The papers [4, 5] consider a vector method for solving one of the important problems of dynamic analysis of flat lever mechanisms with lower kinematic pairs, which consists in determining reactions in kinematic pairs and balancing the moment (force) on the driving link for a given law of motion of the mechanism. In the article [6], the main attention is paid to determining the force or torque acting on a flat mechanism using a numerical method, when the acceleration and dynamic properties of the joints are known. The article [7] developed an analytical interpretation of an approximate method for calculating forces in kinematic pairs taking into account friction forces for the Assur group of the second class with three rotational pairs. In the paper [8], dynamic equations of motion are used for kinetic analysis. Vector/scalar equations are solved using the MathCAD software. The results are verified using the Working Model 2D software. The paper [9] proposes a new design of a lifting mechanism, the peculiarity of which is that in its structure it belongs to the Assur group of a high class, which determines the ease of operation and reliability of the design. For this design, a synthesis of the mechanism was carried out. The work [10] is devoted to the kinetostatic analysis of the ratchet mechanism acting on the conveyor, which is part of the MGL-3 solid organic fertilizer spreader, namely, the reactions in the kinematic connections, as well as the torque in the drive clutch of the mechanism, are determined.

The conducted literature review shows that despite the numerous works devoted to the kinetostatic analysis of various mechanisms, a five-link flat mechanism, which has one higher kinematic pair in its structure, has not been studied.

Formulation and solution of the problem. This paper examines the kinetostatic analysis of a flat five-link mechanism, which, in addition to the lower ones, includes one higher kinematic pair (Fig. 1).

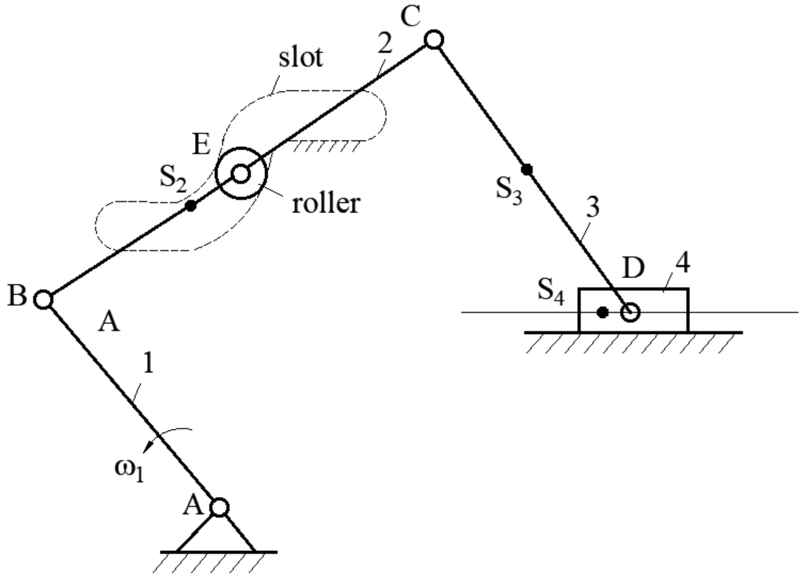

Figure 1. Five-link flat mechanism with one higher kinematic pair.

It is known that a five-link flat-lever mechanism has two degrees of freedom. If a known point of this mechanism moves along a certain trajectory, then this mechanism turns into a mechanism with one degree of freedom. For example, if a roller is placed at point C and forced to move along the trajectory shown in Fig. 1 by a dashed line (slot), then the mechanism will have one degree of freedom. To do this, a slot is made in the fixed post of the mechanism, into which the roller mounted at point C is placed. Then, when the crank AB rotates, point C will move along this slot, and point D will perform the required movement. The synthesis and kinematic analysis of this mechanism are considered in [11].

Here we consider the kinetostatic analysis of the mechanism shown in Fig. 1. It is known that in kinetostatic analysis, unknown forces are determined with a known law of motion of the mechanism. In this case, the reaction forces in kinematic pairs and the balancing force applied to the leading link AB are determined.

In kinetostatic analysis, the resistance forces or driving forces, masses, moments of inertia and the center of mass of the links are specified. According to the known law of motion of the mechanism, the inertial forces and moments of inertial forces of the links are determined. In the force analysis of mechanisms, the d'Alembert principle is used. In this case, the inertial forces of the links are added to the real forces and the problems of dynamics are solved using the equations of statics.

It is known that if the degree of freedom of a kinematic chain is zero, then this chain is statically determinate. A kinematic chain with zero mobility, which is part of a mechanism, is an Assur group. Therefore, in a kinetostatic analysis, the mechanism is divided into structural Assur groups and a primary mechanism. We emphasize that with such a division of the mechanism in the force loading of each structural group, only the reaction forces in the kinematic pairs will be unknown. In the composition of the mechanism under consideration (Fig. 1), in addition to the primary mechanism -

the input link AB with the support, there are two Assur groups. The 4th link - the slider, with the 3rd link - the connecting rod make up the Assur group of the second class. The 2nd link with the roller is called a "monad". Its degree of mobility is zero and is statically determinate:

$$W = 3n - 2p_1 - p_2 = 3 \cdot 1 - 2 \cdot 1 - 1 = 0 \quad (1)$$

First, we consider the force analysis of the structural group consisting of the 4th and 3rd links, which is connected to the last mechanism (Fig.2).

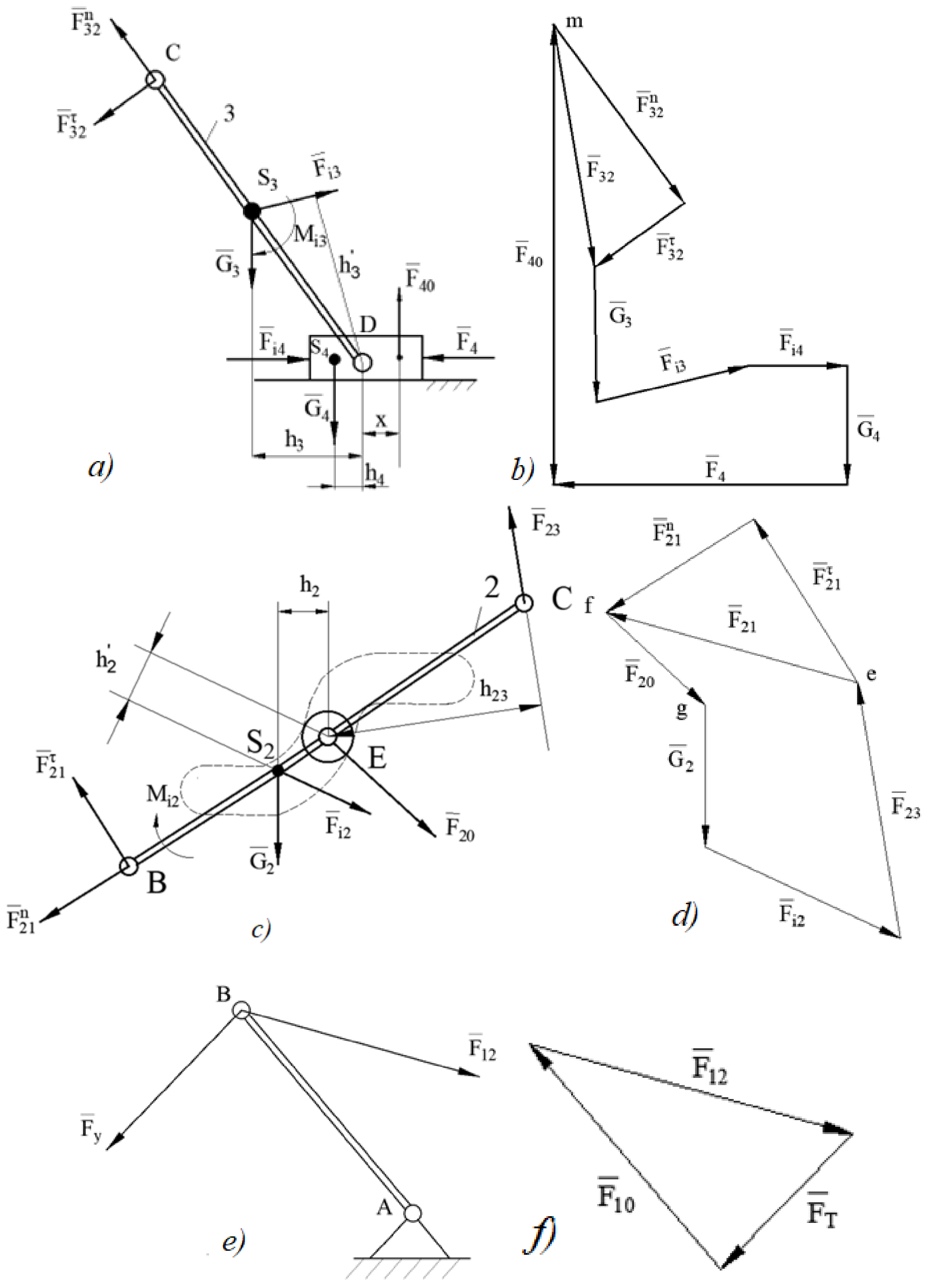

Figure 2. Kinetostatic analysis of a five-link flat mechanism with one higher kinematic pair.

The production resistance force F_4, the gravity force G_4, and the inertial forces of this link F_{i4} acting on the output link – the slider are known (Fig.2*a*). In particular, the gravity force of the 3rd link G_3, the inertial force F_{I3}, and the moment of inertia M_{i3} are known. The reaction force from the support to the slider $\bar{F}_{40}$ is known in direction. This force is directed normally relative to the motion of the slider, its value and the point of application *x* are unknown. In a single-motion rotational kinematic pair located at point *C*, the point of application of the reaction force $\bar{F}_{23} = -\bar{F}_{32}$ arising in it is known. The direction and modulus are unknown. We will decompose the reaction force $\bar{F}_{32}$ into two components, normal and tangential, known in direction but unknown in value: $\bar{F}_{32} = \bar{F}_{32}^{n} + \bar{F}_{32}^{\tau}$. The reaction force $\bar{F}_{32}^{n}$ is directed along the link *CD*, $\bar{F}_{32}^{\tau}$ is perpendicular to the link *CD*.

To determine the reaction force of the structural group consisting of the 3rd and 4th links, we will use the graphoanalytical method. To do this, we first draw up an equation for the moments of forces acting on the 3rd link relative to point *D*:

$$\sum M_D = F_{32}^{\tau} \cdot CD \cdot \mu_l + G_3 \cdot h_3 \cdot \mu_l - F_{i3} \cdot h_3' \cdot \mu_l - M_{i3} = 0 \qquad (2)$$

From here:

$$F_{32}^{\tau} = \frac{F_{i3} \cdot h_3' + M_{i3} \cdot \frac{1}{\mu_l} - G_3 \cdot h_3}{CD}$$

where μ_l - is the scale of the position plan.

To determine the values of $\bar{F}_{40}$ and $\bar{F}_{32}$ based on the selected force scales, we construct a force polygon (Fig.2*b*). When constructing a force polygon, the direction of one of the unknown forces is first noted, for example: $\bar{F}_{32}^{n}$ ends with the directions of the other unknowns - $\bar{F}_{40}$. To construct a force polygon, you can use the following vector equation:

$$\bar{F}_{32}^{n} + \bar{F}_{32}^{\tau} + \bar{G}_3 + \bar{F}_{i3} + \bar{F}_{i4} + \bar{G}_4 + \bar{F}_4 + \bar{F}_{40} = 0 \qquad (3)$$

After constructing the force polygon, the values of the unknown forces are determined:

$$\bar{F}_{32} = mn \cdot \mu_F, \ \bar{F}_{40} = mk \cdot \mu_F,$$

where μ_F is the scale of the force plan.

From the condition of the slider equilibrium, the points of application of the reaction force $\bar{F}_{40}$. are determined. To do this, we compose the equations of the moments of forces acting on the slider:

$G_4 \cdot h_4 - F_{40} \cdot x = 0,$

$$x = \frac{G_4 \cdot h_4}{F_{40}}$$

Reaction forces from the 3rd link to the 2nd link

$$\bar{F}_{23} = -\bar{F}_{32}, \quad \bar{F}_{32} = \bar{F}_{32}^{n} + \bar{F}_{32}^{\tau}, \quad F_{32} = mp \cdot \mu_F.$$

The next stage of the force analysis will be the force analysis of the "monad" - the second link with the roller (Fig.2*c*). Since the roller with the fixed link make up a kinematic pair, the reaction force from the fixed link to the roller $\bar{F}_{20}$ will be normal to the elements of the kinematic pair, that is, normal to the trajectory of point *E*. Then the point of application and the direction of $\bar{F}_{20}$ are known. The reaction force $\bar{F}_{21}$, arising at point B from the leading link to the second link is decomposed into two components:

$$\bar{F}_{21} = \bar{F}_{21}^{n} + \bar{F}_{21}^{\tau}.$$

To determine $\bar{F}_{21}^{\tau}$, we will compose an equation of moments of forces relative to point *E*.

$$\sum M_E = -F_{21}^{\tau} \cdot EB + F_{\prime 2} \cdot h_2' + G_2 \cdot h_2 + F_{23} \cdot h_{23} - M_{i2} \cdot \frac{1}{\mu_l} = 0 \qquad (4)$$

Hence,

$$F_{21}^{\tau}=\frac{F_{i2}\cdot h_2'+G_2\cdot h_2+F_{23}\cdot h_{23}-M_{i2}\cdot\dfrac{1}{\mu_l}}{EB}$$

The values of the reaction forces $\bar{F}_{20}$ and $\bar{F}_{21}^{n}$ are determined by constructing a force polygon (Fig.2*d*). To do this, we use the following vector equation:

$$\bar{F}_{20}+\bar{G}_2+\bar{F}_{i2}+\bar{F}_{23}+\bar{F}_{21}^{\tau}+\bar{F}_{21}^{n}=0 \tag{5}$$

After constructing the force polygon, we find:

$$F_{20}=fg\cdot\mu_F.\ \ F_{21}=ef\cdot\mu_F.$$

At the end of the kinetostatic analysis, the force analysis of the primary mechanism is considered, i.e. the leading link *AB* with the support (Fig.2*d*). From the analysis of this system, the balancing force $\bar{F}_{y}$, the reaction force $\bar{F}_{01}$ arising in the kinematic pair between the support and the link *AB* are determined. $\bar{F}_{y}$ – the balancing force is conditionally applied to point *B* perpendicular to link *AB*. The mass and moment of inertia of the input link *AB* are not taken into account. Then the forces acting on the primary mechanism $\bar{F}_{01}$, $\bar{F}_{21}$ and $\bar{F}_{y}$ intersect at one point. The values of $\bar{F}_{01}$ and $\bar{F}_{y}$ are determined by constructing a force triangle (Fig.2*f*).

Conclusion.

Based on the above, the following conclusions can be made:

1. A kinetostatic analysis of a five-link flat mechanism, which in addition to the lower ones includes one higher kinematic pair, was carried out using the graphoanalytical method;

2. Adding one higher kinematic pair to a flat lever mechanism with two degrees of freedom turns it into a mechanism with one degree of freedom;

3. Using the d'Alembert principle, the reaction forces arising in kinematic pairs were determined;

4. A force analysis of the primary mechanism was considered and the balancing force was determined.

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