ANALYSIS OF A COMPLEX PLANAR MECHANISM OF THE THIRD CLASS WITH TWO TRANSLATIONAL AND OTHER ROTATIONAL KINEMATIC PAIRS

Koshel S.[1], Koshel G.[2], Zaliubovskyi M.[2], Kovalyov Y.[1], Popovichenko S.[3]
[1]Kyiv National University of Technology and Design, Ukraine
[2]Open International University of Human Development "Ukraine", Ukraine.
[3]Kyiv State Academy of Decorative and Applied Arts and Design named after Mykhailo Boychuk, Ukraine

Abstract. In various fields of mechanical engineering, complex planar lever mechanisms with structural groups of links of the third, fourth, and higher classes are widely used. Conducting research on such mechanisms involves a systematic sequence of actions, with significant emphasis placed on their structural and kinematic analysis.
In the article, we performed a structural analysis of a complex planar mechanism of the third class with two translational and other rotational kinematic pairs. We considered all possible variants of structural transformation of the third-class mechanism under the condition of selecting other possible driving links and obtained corresponding structural formulas.
We developed a sequence of actions and, using graph-analytical methods, conducted a kinematic analysis of a third-class mechanism with two translational and other rotational pairs in a manner characteristic of second-class mechanisms. In our investigation, we took into account the property of planar mechanisms of higher classes to structurally modify their construction formula depending on the selected initial mechanism.
Keywords: Structural analysis, kinematic analysis, planar mechanism, structural group, link of mechanism.

Introduction

In various fields of mechanical engineering, mechanical systems are widely used, the basis of which are complex planar lever mechanisms with structural groups of links of the third, fourth, and higher classes. The main advantages of such articulated lever mechanisms compared to others include the complexity of geometric trajectories and the motion laws of their individual points along with the working elements of the equipment, which allows them to perform technological operations.

The analysis of such mechanisms is relevant firstly because it requires developing a specific sequence of actions, which will be characteristic for a particular complex mechanism of the third class or higher. Secondly, the number of works related to conducting such research is insufficient to populate electronic databases in this scientific direction, in order to create software in the future that would automate the process in engineering design [1] of complex planar mechanical systems.

Conducting research on planar mechanisms involves a systematic sequence of actions, in which significant importance is given to their structural analysis [2, 3]. This is because during the investigation of the structural components and linkages from which they are composed, structural regularities in their construction [4] can be observed. This, in turn, allows for determining the optimal sequence for further kinematic [5, 6] and dynamic investigations [7]. The structural analysis of a complex mechanism of the third class or higher can serve as a basis for performing kinematic analysis of a complex planar mechanical system, for instance, in a graph-analytical manner [8]. The analysis and synthesis of spatial mechanical systems are also relevant for addressing design challenges and improving mechanisms used in the fashion industry [9].

Results and discussion

The mechanism of the third class (Fig. 1) with one driving link, two translational and other rotational kinematic pairs is formed using eight links. The body of the mechanism (link 0) is stationary, links 1 and 5 participate in forming stationary kinematic pairs O_1, O_2 and have rotational motion, sliders 4 and 7 move relative to stationary guides xx and yy, respectively. Other links (connecting rods 2, 3, 6) have complex planar-parallel motion, which is formed by the geometric combination of two motions - translational motion along with an arbitrarily chosen pole and relative motion around it. Among the links of the mechanism, there is one complex link (connecting rod 3), which simultaneously has four elements of kinematic pairs, forming rotational kinematic pairs B, C, K, E with links 2, 4-6, respectively.

The third-class mechanism is structurally formed by attaching to the initial mechanism (a combination of the driving link 1, the frame 0 connected by the kinematic pair O_1) a structural group of third-order third-class links (links 2-5) and second-order second-class links (links 6, 7). The structural formula of the mechanism's construction is provided in Fig. 2.

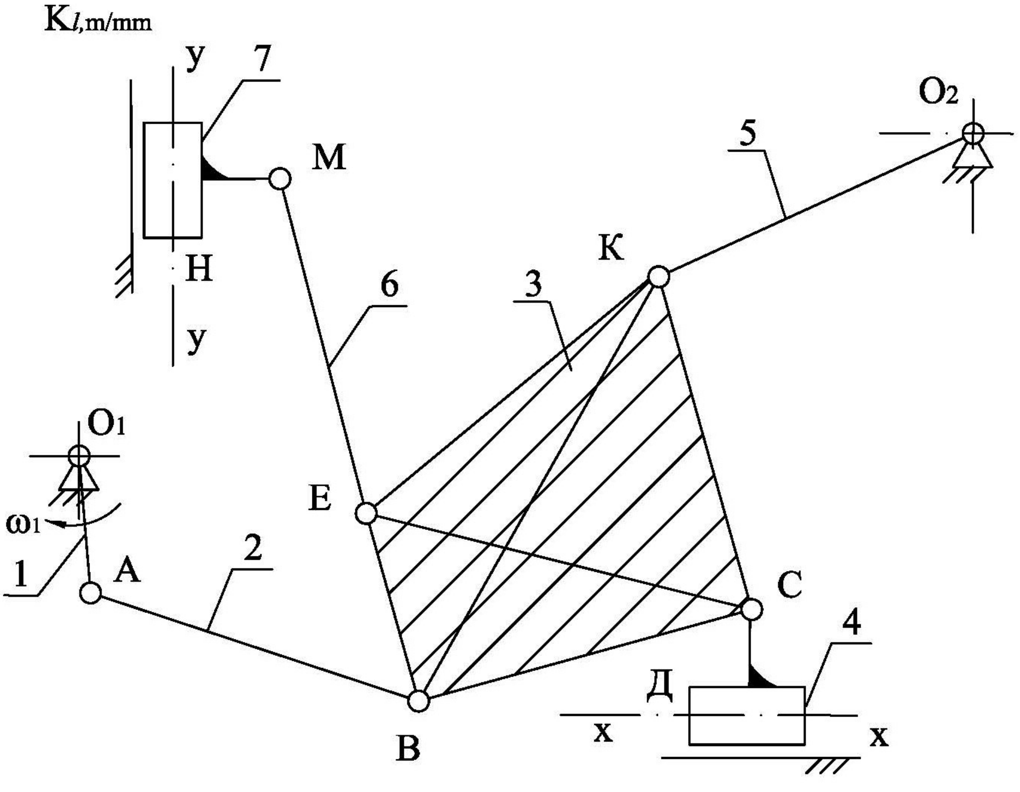

Fig. 1. Kinematic scheme of the third-class mechanism with two translational and other rotational kinematic pairs.

1 class (links 0, 1) → 3 class 3 order (links 2 - 5) → 2 class 2 order (links 6, 7)

Fig. 2. Structure formula

The complexity of further kinematic analysis of such a mechanism using the graph-analytical method lies in the sequential connection of links in the structure of the mechanical system, which have planar-parallel motion, and the kinematic parameters of which are unknown quantities. This situation precludes the composition of systems of vector equations that would have a graphical representation for their solution. Indeed, when composition kinematic equations for point B, it is necessary to utilize known in advance (defined) parameters of two other points, which would belong to two different links 2, 3, forming the kinematic pair B. With point A belonging to link 2, everything is clear (the point belongs to the driving link of the mechanism). However, there is uncertainty in the kinematic parameters of points coinciding with the centers of the kinematic pairs C, K, E of link 3, which prevents the resolution of vector equations regarding the kinematic parameters of point B. To investigate such a third-class mechanism, it is necessary to use a method based on determining the position of a "special" point [10] of the complex base link of the structural group of third-order third-class links. These actions complicate graphical constructions and the entire process of solving the problem using the graph-analytical method.

Note that for mechanisms with one degree of mobility, the unit of sequential kinematic analysis is proposed to be conducted from the initial mechanism towards the structural groups of links connected to the driving link according to their actual configuration (Fig. 2). The result of such analyses carried out graph-analytically, yields graphical representations in the form of velocity and acceleration diagrams, where vectors of absolute velocities and accelerations of mechanism points are constructed from an arbitrarily selected fixed point on the plane (the pole of construction) in a preselected scale.

We propose constructing velocity diagrams in an arbitrarily chosen, no-determined scale, considering a sequence that takes into account the selection of conventionally different possible initial mechanisms within the structure of the actual third-class mechanism [8]. Three such possible initial mechanisms have been identified, corresponding to the number of kinematic pairs formed by the moving links of the mechanism with a frame.

The configurations of third-class mechanism structures under the condition of selecting other possible initial mechanisms are depicted in Figures 3 to 5:

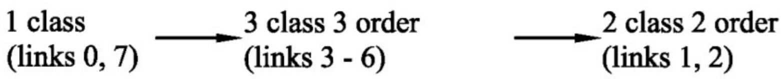

Fig. 3. Structure formula

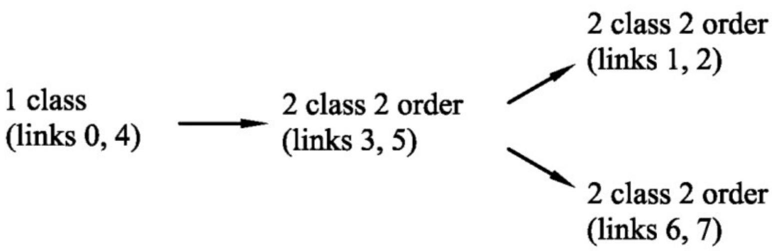

Fig. 4. Structure formula

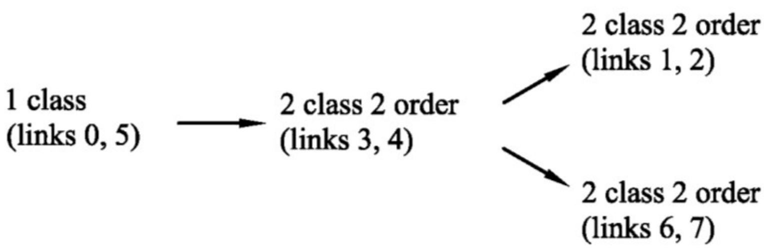

Fig. 5. Structure formula

From the analysis of the obtained structural configuration formulas, it can be concluded that the conditional selection of another possible driving link significantly affects the structural sequence of linking groups of links and their structural composition.

If slider 7 is conditionally chosen as the driving link in the mechanism (Figure 3), the mechanism remains structurally a third-class mechanism with a corresponding change in the links entering the structural groups of third and second classes, in which the driving link 7 executes a translational motion.

Significant structural changes are observed when link 4 or 5 is conditionally chosen as the driving link. According to the obtained structural configuration formulas (Figures 4, 5), in both cases, we observe a decrease in the class of the mechanism under investigation by one unit. If, conditionally, we select the combination of slider 4 and the frame 0 as another initial mechanism, forming a translational kinematic pair D (or the structural combination of links 5, 0, and the rotational kinematic pair O_2), then the third-class mechanism structurally transforms into a second-class mechanism with three structural groups of second-class links of the second order.

From the above, we can conclude that a third-class mechanism with two translational and other rotational kinematic pairs can be analyzed using a graph-analytical method in a sequence that corresponds to the investigation of a mechanical system with structural groups of second-class links of the second order.

We will perform the kinematic analysis of the mechanism for the position shown in the kinematic scheme (Figure 1), under the condition that the crank 1 has a constant angular velocity ω_1 = -100 rad/s (the "-" sign indicates that the direction of the angular velocity is clockwise). The following geometric parameters of link lengths are considered known:
l_{O1A} = 25 mm, $l_{AB} = l_{BC} = l_{CK} = l_{KO2} = l_{ME}$ = 60 mm, and l_{EK} = 65 mm.

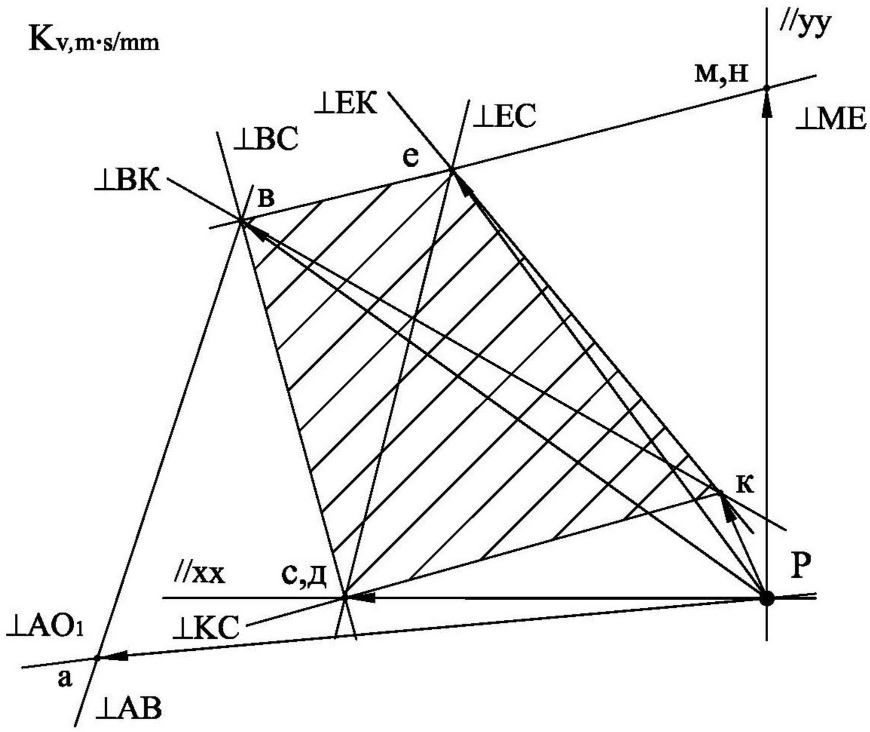

Fig. 6. Plan of velocity of a third-class mechanism with two translational and other rotational kinematic pairs.

We conduct the analysis of the mechanism using a graph-analytical method in the sequence determined by the structural configuration formula (Figure 5), which corresponds to the case where link 5 is conditionally chosen as the potentially movable link in the conditionally selected alternative initial mechanism. We graphically construct the plan of velocity (Figure 6) in an arbitrarily chosen scale, meaning the length of the vector $\overrightarrow{P\kappa}$ on the plan of velocity is represented by an arbitrary length in a direction chosen arbitrarily (for example, clockwise) along a line perpendicular to the segment KO_2.

We make a system of vector equations determining the membership of point C to links 3 and 4, taking into account that points C and D belong to slider 4, hence their velocities are equal in magnitude and direction:

$$\begin{cases} \vec{V}_C = \vec{V}_K + \vec{V}_{C;K} \\ \vec{V}_C = \vec{V}_Д = \vec{V}_{Дcm} + \vec{V}_{Д;Дcm} \end{cases}, \tag{1}$$

where point $Д_{cm}$ belongs to the fixed link, therefore $\vec{V}_{Дcm} = 0$.

We determine the position of point «c» on the plan of velocity as a result of vectorially solving system of equations (1). Then, we construct the vector $\overrightarrow{Pc}$ of the absolute velocity of point C and determine the vector $\vec{V}_C = \vec{V}_Д$ on the plan.

We make a system of vector equations to determine the velocity vectors of points B and E, taking into account that both points belong to the connecting rod 3, which is a complex link:

$$\begin{cases} \vec{V}_B = \vec{V}_K + \vec{V}_{B;K} \\ \vec{V}_B = \vec{V}_C + \vec{V}_{B;C} \end{cases}, \qquad \begin{cases} \vec{V}_E = \vec{V}_K + \vec{V}_{E;K} \\ \vec{V}_E = \vec{V}_C + \vec{V}_{E;C} \end{cases} \tag{2}$$

The result of the vectorial solution of these systems of equations is the determination of the positions of the end points «в» and «e» of the velocity vectors $\vec{V}_B$ and $\vec{V}_E$ on the velocity diagram.

The membership of point M to two different links, 6 and 7, and the fact that points M and H are points of slider 7, are determined by the following system of vector equations:

$$\begin{cases} \vec{V}_M = \vec{V}_E + \vec{V}_{M;E} \\ \vec{V}_M = \vec{V}_H = \vec{V}_{Hcm} + \vec{V}_{H;Hcm} \end{cases}, \tag{3}$$

where point H_{cm} belongs to the fixed link, therefore $\vec{V}_{Hcm} = 0$.

We determine the position of point «м» and the length of the vector $\vec{V}_M = \vec{V}_H$ graphically.

We make a system of vector equations that allows us to determine the length of the vector $\overrightarrow{Pa}$ on the plan, satisfying an arbitrarily chosen scale, in which the velocity plan is constructed:

$$\begin{cases} \vec{V}_A = \vec{V}_B + \vec{V}_{A;B} \\ \vec{V}_A = \vec{V}_{O_1} + \vec{V}_{A;O_1} \end{cases} \tag{4}$$

It is important to note the necessity of verifying that the direction of rotation of the conditionally chosen alternative driving link 5 has been selected correctly. We find the direction of the angular velocity of link 1 along the direction of the obtained vector $\overrightarrow{Pa}$ on the velocity plan. In our case, there is a coincidence of this direction with the one specified by the task condition, indicating the correct selection of the direction of motion for the conditionally chosen crank 5. In the case of different directions, it is necessary to repeat the construction of the velocity plan under the condition of changing the direction of rotation of the conditionally chosen crank 5 to the opposite.

We calculate the actual velocity magnitude of point A as a point belonging to the driving link of the mechanism:

$$V_A = \omega_1 \cdot l_{O_1A_1} = 100 \cdot 0{,}025 = 2{,}5 \ \text{m} \cdot \text{s}. \quad (5)$$

The magnitude of the velocity plan scale is determined from the equation:

$$K_V = \frac{V_{A_1}}{P_{a_1}} = \frac{2{,}5}{116{,}9} = 0{,}022 \ \text{m} \cdot \text{s /mm}. \quad (6)$$

We calculate the actual magnitudes of the angular velocities of all links of the third-class mechanism:

$$\omega_2 = \frac{V_{A;B}}{l_{AB}} = \frac{ав \cdot K_V}{l_{AB}} = \frac{79{,}3 \cdot 0{,}022}{0{,}06} = +29{,}1 \ \text{rad/s}.$$

$$\omega_3 = \frac{V_{C;K}}{l_{CK}} = \frac{ск \cdot K_V}{l_{CK}} = \frac{68{,}1 \cdot 0{,}022}{0{,}06} = -25{,}0 \ \text{rad/s}.$$

$$\omega_5 = \frac{V_K}{l_{KO_2}} = \frac{Рк \cdot K_V}{l_{KO_2}} = \frac{20{,}5 \cdot 0{,}022}{0{,}06} = -7{,}5 \ \text{rad/s}.$$

$$\omega_6 = \frac{V_{M;E}}{l_{ME}} = \frac{ме \cdot K_V}{l_{ME}} = \frac{65{,}4 \cdot 0{,}022}{0{,}06} = -20{,}7 \ \text{rad/s}, \quad (7)$$

where $ав; ск; Рк; ме$, mm – the corresponding lengths of segments on the velocity plan;

$l_{AB}; l_{CK}; l_{KO2}; l_{ME}$ – lengths of the corresponding links, m.

The "-" sign of the angular velocity magnitude indicates that its direction coincides with the clockwise direction, while the "+" sign indicates that its direction is opposite to the clockwise direction.

Conclusions

A structural analysis of a complex planar third-class mechanism with two translational and other rotational kinematic pairs has been conducted, considering all possible structural transformations under the condition of choosing other possible driving links. Using a graph-analytical method that takes into account the property of planar mechanisms to structurally change their configuration depending on the chosen initial mechanism, a kinematic analysis of the third-class mechanism has been carried out in a manner characteristic of second-class mechanisms.

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