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# ANALYSIS FLAT MECHANISM OF THE FOURTH CLASS WITH A MOVING CLOSED LOOP AND THREE COMPLEX LINKS

*С. Кошель, Г. Кошель.* **Аналіз плоского механізму четвертого класу з рухомим замкненим контуром та трьома складними ланками**. Дослідження складних структурних груп ланок плоских механізмів дозволяє вдосконалювати існуюче технологічне обладнання та проектувати нові машини, в яких за допомогою механізмів на основі структурних груп четвертого та вище класів може бути забезпечено виконання інноваційних технологічних процесів виробництва. Кінематичний аналіз складних плоских механізмів четвертого та вище класів з урахуванням індивідуальних підходів що до їх досліджень, безумовно, є актуальними, а застосування таких механізмів все частіше спостерігається в сучасному обладнанні, що забезпечує виконання технологічних процесів на підприємствах індустрії моди. В роботі розроблена послідовність дій для знаходження векторів швидкостей точок механізму четвертого класу з рухомим замкненим контуром, який утворений чотирма ланками, три з яких мають вигляд складних ланок. Визначено лінійні вектори швидкостей точок, що співпадають з геометричними центрами кінематичних пар структурної групи ланок четвертого класу третього порядку плоского механізму, в якому умовно зроблено зміну початкового механізму на інший структурно можливий. Для проведення кінематичного аналізу механізму запропонованоураховувати наявність складних ланок в його структурі, а саме структурну особливість утворення послідовного з'єднання трьох ланок в кінематичний ланцюг типу «коромисло – шатун – коромисло», що дозволило визначити положення миттєвого центру швидкостей ланки, яка має плоско паралельний рух. Умовне обертання іншої умовно ведучої ланки навколо такого миттєвого центру обертання дозволило спростити графічні побудови дослідження. Застосування графоаналітичного методу дозволило виконати векторні графічні побудови в довільно обраному масштабі для всього механізму, а по їх завершенню виконати уточнюючі розрахунки масштабу певної векторної побудови.
*Ключові слова*: кінематичне дослідження, кінематичний аналіз, вектор швидкості, план швидкостей

*S. Koshel, G. Koshel.* **Analysis flat mechanism of the fourth class with a moving closed loop and three complex links.** The study of complex structural groups of links of flat mechanisms allows to improve the existing technological equipment and design new machines. Such mechanisms, based on structural groups of the fourth and higher classes, can ensure the implementation of innovative technological processes of production. Kinematic studies of complex flat mechanisms of the fourth class and higher are certainly relevant, if we take into account the individual approach to their research. The use of such mechanisms is increasingly observed in modern equipment that ensures the execution of technological processes at enterprises of the fashion industry. The work developed a sequence of actions for finding the velocity vectors of the points of the fourth-class mechanism with a moving closed loop, which is formed by four links, three of which have the form of complex links, is developed. The linear vectors of the velocities of the points coinciding with the geometric centers of the kinematic pairs of the structural group of links of the fourth class of the third order were determined. We conditionally changed the input mechanism to another structurally possible in a flat mechanism. The research was carried out using the graph-analytical method. In order to carry out a kinematic analysis of the mechanism, it is proposed to take into account the presence of complex links in its structure, namely the structural feature of the formation of a sequential connection of three links in a kinematic chain of the type "rocker arm – connecting rod – rocker arm". This made it possible to determine the position of the instantaneous center of velocity of the link, which has plane-parallel motion. Conditional rotation of another conditionally leading link around such an instantaneous center of rotation made it possible to simplify the graphic constructions of the study. The application of the graph-analytical method made it possible to perform vector graphic constructions in an arbitrarily chosen scale for the entire mechanism, and after their completion, to perform detailed calculations of the scale of a certain vector construction.
*Keywords*: kinematic research, kinematic analysis, velocity vector, velocity plan

## Introduction

The study of complex structural groups of links of flat mechanisms allows to improve the existing technological equipment for enterprises of the fashion industry and to design new machines. In them, with the help of mechanisms based on structural groups of the fourth and higher classes, it is possible to ensure the implementation of innovative technological processes of production.

At the moment, the most developed methods are the research of structural groups of links, which include two moving links and three kinematic pairs. There are methods that allow for the analysis of structural groups of links, in which there are four moving links and six kinematic pairs as part of mechanisms of the third class. As for mechanisms of the fourth class based on such structural groups, it is possible to structurally consider such mechanisms conditionally as mechanisms of the third class.

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For example, when conducting research using the graphoanalytic method, which allows you to start research in the form of vector graphic constructions on an arbitrarily chosen scale, after completing the vector construction for the entire mechanism, perform detailed calculations of the scales of certain vector constructions. It is not possible to perform the analysis in such a sequence using an analytical method. The reason is that for the analytical calculation of the kinematic parameters of the mechanism, it is necessary to compile a research algorithm so that the solution of the problem is based on parameters that are known or on those that are previously determined or calculated.

Based on structural groups of links, which include six links and nine kinematic pairs, a significant number of variants of complex flat mechanisms can be synthesized. For example, the mechanism of the third class with two complex links, the mechanisms of the fourth class with three and four complex links, the mechanisms of the fifth and sixth classes with three complex links, etc.

Such mechanisms, on the one hand, do not have well-known methods of kinematic research and require the development of an individual sequence of analysis in each individual case. On the other hand, they have significant prospects for application in the mechanisms of technological equipment because they can ensure the movement of the working bodies of machines along complex trajectories and laws of motion.

**Analysis of basic research and publications**

Mechanical technologies nowadays have a new level of development, which is connected with the use of mechatronic systems in modern manufacturing processes and individual machines. Innovations in technologies are impossible without complex mechanisms and their comprehensive analyses. Unfortunately, at the moment there is a problem of insufficient study of issues related to the research of complex mechanisms with structural groups of links of the fourth and higher grades due to the relative complexity of their implementation and the lack of their required number. The relevance of the problems of kinematic analysis of mechanisms is indirectly confirmed by a significant number of publications in recent years, which are devoted to the research of complex mechanisms of higher classes. Thus, classical issues of structural and kinematic research of mechanisms are given attention in a number of works. Some consider the issue of synthesis of mechanisms [1, 2], while in works [3, 4] the synthesis is performed according to certain given kinematic parameters, in others - kinematic analysis is carried out [5, 6], and in works [7, 8] for kinematic research, graphic research methods. Work [9] provides a kinetostatic calculation of a complex mechanism of fashion industry equipment, and work [10] is devoted to the study of the mechanism of the fourth class. In paper [11], the issues of research of a complex seven-link mechanism are considered, and in paper [12] – a mechanism with the presence of a closed loop in its structure.

**The aim of the study**

The purpose of the work is to develop sequences of actions for the kinematic study of the velocities of the points of a flat mechanism with a moving closed circuit, which is formed by four links, three of which have the form of complex links. The points that coincide with the geometric centers of the kinematic pairs of the structural group of the fourth class of the third order are subject to investigation. The analysis of the mechanism must be carried out by the grapho-analytical method, taking into account the provisions of the theory of mechanisms and machines course on the property of mechanisms to change their class depending on the conditionally selected leading link, which is part of the driven structural groups of the mechanism links.

**Presentation of the main material**

In Fig. 1 presents a complex planar hinge-lever mechanism of the fourth class, which consists of a crank *1* connected to a riser 0 and other driven links *2 – 7*, among which links *2*, *3*, *5*, *6* have plane-parallel movement, and links *4*, *7* – rotary.

The mechanism of the first class (set of links 0, *1*) together with the structural group of links of the fourth class of the third order, which includes six links *2 – 7* and nine kinematic pairs of the fifth class A, B, D, $O_3$, C, K, E, M, $O_2$ form a mechanism of the fourth class with one degree of mobility in relation to the fixed body, that is, a mechanism with one driving crank. The formula of the structure of the mechanism takes the form:

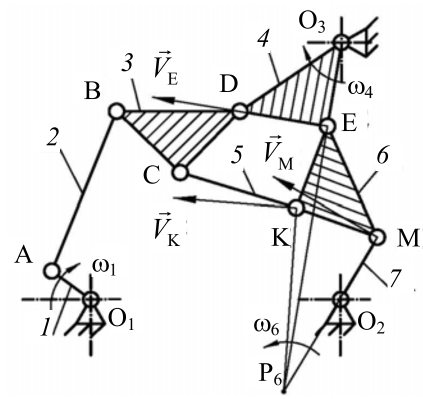


**Fig. 1.** Kinematic scheme of the mechanism

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*1 class (links 0, 1) → 4 class 3 order (links 2 – 7).*

The presence of variable geometry of the closed circuit C, D, E, K is a structural feature of the mechanism. The contour is formed by the rocker arm DE and three connecting rods CD, CK, EK, two of which CD and EK have the form of complex links and are located opposite each other (connecting rod *3* forms three kinematic pairs with other links, two of which are created with other connecting rods *2* and *5*, and the third – with rocker arm *4*, connecting rod 6 carries three elements of kinematic pairs, two of which take part in the formation of pairs with two different rocker arms *4* and *7*, and the third – with connecting rod *5*).

The problem that arises during the kinematic analysis of such a mechanism by a graph analytical method is that it is not possible to carry out research using well-known methods of analysis of complex mechanisms of the third class. This is due to the fact that connecting rod *2*, on the one hand, is directly connected to crank *1* by a kinematic pair A (that is, the kinematic parameters of point A are known), and on the other hand, it is connected to connecting rod *3*, which in turn is connected to two it is connected by kinematic pairs to two more moving links (to connecting rod *5* and rocker arm *4*, respectively, by kinematic pairs C and D), the kinematic parameters of which are unknown.

The given parameters for the kinematic analysis of the mechanism of the fourth class are the angular velocity of the driving link *1* ($\omega_1$=const, $c^{-1}$) and the length scale ($K_l$, m/mm), in which the kinematic diagram of the mechanism is constructed.

To conduct a kinematic study, we use the graph analytical method and use the provisions of the theory of mechanisms and machines courses on kinematic studies of plane mechanisms and theoretical mechanics, which relate to the study of plane-parallel motion of a rigid body. A structural feature of complex flat mechanisms is the property of mechanisms of higher classes with one initial mechanism to change their class under the condition of replacing the driving crank with another conventional structurally possible one.

If the leading link of the mechanism is conventionally chosen as a complex link *4* or a rocker arm *7*, which have fixed axes of rotation determined by kinematic pairs, $O_3$ and $O_2$, respectively, then the mechanism of the fourth class structurally takes the form of a mechanism with structural groups of links of a smaller class, whose structural formulas have the following view:

*1 class (links 0, 4) → 2 class 2 order (links 6, 7) →2 class 2 order→(links 3, 4) →*
*→ 2 class 2 order (links 1, 2);*
*1 class (links 0, 7) → 2 class 2 order (links 4, 6) →2 class 2 order→(links 3, 5) →*
*→ 2 class 2 order (links 1, 2).*

The obtained formulas of the structures of the mechanism of the fourth class with a moving closed circuit formed by connecting rod *5* and three complex links, two of which are connecting rods *3* and *6* located opposite each other, and the third is rocker arm *4*, which connects them, allow us to develop a sequence of actions for further kinematic study of the mechanism and make them more accurate by reducing the class of the mechanism with a conditionally different possible initial mechanism. From the formulas, we can see that if rockers *4* or *7* are conventionally chosen as cranks, the mechanism of the fourth class conditionally takes the form of a mechanism of the second class, in the structure of which there is one initial mechanism with a conditionally different possible leading link, to which three structural groups of the second are sequentially joined class of the second order.

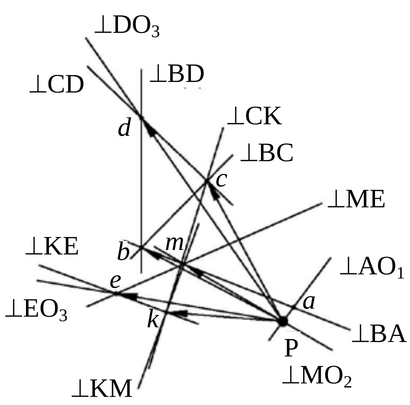

**Fig. 2.** Velocity plan of the mechanism of the fourth class

We begin the kinematic study by assuming the motion of a conditionally different driving link, for example, *4* in magnitude and direction (that is, we arbitrarily choose the angular velocity $\omega_4$ of the double-armed rocker arm *4*). For this purpose, on the velocity plan (Fig. 2) we put a vector $\vec{P}e$ (or $\vec{P}d$ ) of arbitrary length, the direction of which coincides with the direction of the perpendicular to the line $O_3E$ (or $O_3D$), while the direction of the angular velocity $\omega_4$ is chosen arbitrarily, for example, in the direction of clockwise movement. If we first set aside the vector $\vec{P}e$, then we build the length of the vector $\vec{P}d$ taking into account the linear proportionality of the triangles $EO_3D$ and *ePd*, respectively, on the kinematic diagram and the velocity plan.

We compile a system of vector equations to determine the velocity vector of point M:

$$\left. \begin{cases} \vec{V}_{M} = \vec{V}_{E} + \vec{V}_{M;E} \\ \vec{V}_{M} = \vec{V}_{O_2} + \vec{V}_{M;O_2} \end{cases} \right\}. \quad (1)$$

We graphically solve the system of vector equations (1) and determine the vector $\vec{P}m$ on the velocity plane. On the condition that the points E, M, K belong to one complex link 6 and according to the similarity theorem of the theory of mechanisms and machines course, we determine the position of the point "*k*" of the velocity vector $\vec{V}_K$ on the velocity plane. We compile a system of vector equations to determine the velocity vector of point C:

$$\left. \begin{cases} \vec{V}_{C} = \vec{V}_{D} + \vec{V}_{C;D} \\ \vec{V}_{C} = \vec{V}_{K} + \vec{V}_{C;K} \end{cases} \right\}. \quad (2)$$

We graphically solve the system of vector equations (2) and determine the vector $\vec{P}c$ on the velocity plane. We determine the position of point "*b*" – the end of the velocity vector $\vec{V}_B$ on the velocity plane. To determine the position of point "*b*", we apply the condition that points D, C, B belong to complex link *3*, i.e., according to the similarity theorem, triangles DCB and dcв are similar.

We compile a system of vector equations to determine the velocity vector of point A:

$$\left. \begin{cases} \vec{V}_{A} = \vec{V}_{B} + \vec{V}_{A;B} \\ \vec{V}_{A} = \vec{V}_{O_1} + \vec{V}_{A;O_1} \end{cases} \right\}. \quad (3)$$

The velocity vector $\vec{V}_A$ on the velocity plane allows you to determine the direction of the angular velocity of link *1*, which is the actual crank of the fourth-class mechanism. If the obtained direction coincides with the direction of rotation of the driving link given by the condition of the study, it means that the direction of movement of another conditionally possible crank (in the case of our study, crank *4*) was correctly chosen. If the found direction of rotation of the link *1* does not coincide with the valid specified direction of rotation of the crank *1*, it is necessary to repeat the study under the condition of the rotation of a conditionally different structurally possible crank *4* opposite to the direction that was previously chosen. In our research case, we have confirmation of the correct selection of the direction of rotation of the conditionally different crank *4* in the direction of clockwise movement, because for the obtained direction of the vector $\vec{V}_A$, the direction of the angular velocity of link 1 coincides in direction with the movement of the leading link of the fourth-class mechanism. The graphic construction where the vectors of linear velocities of the points that coincide with the centers of the corresponding kinematic pairs of the mechanism of the fourth class of deposition in a vector form from one pole is perceived as a plan of velocities built on an indefinite scale. We determine the scale of the speed plan under the condition of the given dimensions of the links and the given angular velocity of the actual leading link of the mechanism.

Finally, we note that in order to simplify the kinematic analysis of the fourth-class mechanism with a moving closed circuit and three complex links, it can be taken into account that the connecting rod *6*, which has the form of a complex link, forms kinematic pairs E and M, respectively, with two rockers *4* and *7*, rotating around the fixed centers of rotation $O_3$ and $O_2$. (Fig. 1) Velocity vectors $\vec{V}_E$ and $\vec{V}_M$ have directions along the perpendiculars, respectively, to lines $EO_3$ and $MO_2$, therefore, to determine the position of the instantaneous center of velocity (I.C.V.) of connecting rod 6 (point $P_6$) it is necessary from points E and M on the plan position of the mechanism to build perpendiculars to the directions of these speeds, and in fact – to extend the axial lines of links $EO_3$ and $MO_2$ to their intersection.

Further kinematic research is carried out for the case of conditional instantaneous rotation of connecting rod 6 around point $P_6$ with an arbitrarily chosen angular velocity $\omega_6$. Therefore, we conditionally specify the value of the linear velocity of point M (the direction of the velocity vector of this point is directed perpendicular to the segment by which it is connected to point $P_6$). According to the

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direction of speed $\vec{V}_M$, the direction of instantaneous rotation of complex link 6 around I.C.V. will be counter-clockwise. Determine the magnitude of the angular speed of rotation of link 6 around I.C.V.: $\omega_6 = \vec{V}_M / l_{P_6M}$ , $s^{-1}$. The lengths of the velocity vectors of the other two points E and K of link 6 will be proportional to the respective distances of these points to point $P_6$ on the kinematic diagram, and the direction of the vectors is perpendicular to the segments connecting them to I.C.V. Based on the similarity of the triangles $EO_3D$ and *ePd*, we determine the length of the velocity vector $\vec{V}_D$ on the velocity plan, and with the help of systems of vector equations (2) and (3), we complete the velocity plan (Fig. 2).

**Conclusions**

A sequence was developed and kinematic analysis was performed using the graph analytic method to determine the velocity vectors of the points of the fourth-class mechanism with a moving closed circuit, which is formed by four links, three of which have the form of complex links. It is based on the property of mechanisms of a higher class to change class under the condition of choosing another conditionally possible leading link of the mechanism.

It is the presence of three complex links that have a serial connection that made it possible, with the conditional selection of another structurally possible initial mechanism, to lead the solution of the problem of kinematic analysis of a complex planar mechanism of the fourth class to the sequential study of structural groups of links of the second class and to perform such an analysis using the graph analytic method. The presence of a connecting rod in the structure of the mechanism of the fourth class in the form of a complex link, in combination with taking into account its kinematic connection with two different rockers, made it possible to geometrically determine the position of the instantaneous center of speeds of the link, which has plane-parallel motion. In addition, the assumption of choosing this link as a leading link, which instantly rotates around it and sets the movement of the mechanism of the fourth class, made it possible to simplify the kinematic study, and in some cases, the analysis of complex mechanisms of higher classes, to make it possible. Thus, we suggest taking into account the presence of complex links in the structure of flat mechanisms of higher classes and the nature of their connection when conducting similar studies.

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