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ANALYSIS OF FOURTH-GRADE FLAT MACHINES WITH MOVABLE CLOSE-CYCLE FORMED BY THE RODS AND TWO COMPLEX LINKS

С.О. Кошель, Г.В. Кошель. **Аналіз плоских механізмів четвертого класу з рухомим замкненим контуром, утвореним шатунами і двома складними ланками.** Складні багатоланкові плоскі механізми все частіше застосовуються в технологічному обладнанні легкої промисловості. Відсутність універсального способу кінематичного дослідження таких механізмів зумовлює актуальність робіт з кінематичного аналізу багатоланкових механізмів. ***Мета***: Метою роботи є розробка алгоритму кінематичного дослідження швидкостей точок, що співпадають з геометричними центрами кінематичних пар структурної групи четвертого класу третього порядку з рухомим замкненим контуром, утвореним шатунами і двома складними ланками. ***Матеріали і методи***: Для досягнення мети дослідження використано графоаналітичний метод кінематичного дослідження. Розробка алгоритму базується на положеннях теорії механізмів і машин про властивість механізмів вищих класів змінювати клас в залежності від умовно обраного іншого можливого початкового механізму, що входить до складу ведених структурних груп ланок механізму, і положеннях теоретичної механіки щодо миттєвого центра швидкостей. ***Результати***: Визначено вектори швидкостей точок ланок групи Ассура 4-го класу 3-го порядку складного плоского механізму графоаналітичним методом, в якому умовно змінено початковий механізм, що привело до зменшення класу механізму і дозволило дослідити його. На відміну від відомого методу помилкових положень, який застосовується для дослідження структурних груп 3-го класу, запропонований алгоритм кінематичного аналізу дозволяє дослідити механізми 4-го класу без необхідності перебудовування плану, який був побудований в невизначеному масштабі, з подальшим розрахунком дійсного масштабного параметра виконаної графічної побудови.
Ключові слова: механізм; кінематичне дослідження, вектор швидкості, план швидкостей.

S.O. Koshel, G.V. Koshel. **Analysis of fourth-grade flat machines with movable close-cycle formed by the rods and two complex links.** Complex multielement mechanisms are increasingly used in the technical equipment of consumer industry. The lack of a universal method of kinematic research of these mechanisms asserts the relevance of work on the kinematic analysis of multielement mechanisms. ***Aim:*** The aim of this research is to develop an algorithm kinetic research of velocities of the points that coincide with geometric centers kinematic pairs of structure group of the 4th class and 3rd order with movable close-cycle formed by connecting rod and two complex links. ***Materials and Methods:*** The graphic-analytical method of a kinematic research will be used to achieve the goals of research. Development of an algorithm is based on provisions of the theory of mechanisms and engines about property of high classes mechanisms to change its class depending on another possible initial mechanism chosen conditionally which comes to structure of the conducted structural groups of the mechanism links and provisions of theoretical mechanics relatively to instantaneous center of speeds. ***Results***: Velocity vectors of points of Assur group links of the 4th class and 3rd order of the composite flat mechanism are determined by a graphic-analytical method, where the initial mechanism speeds that led to decrease of a class of the mechanism and allowed to investigate it. Unlike the known erroneous statements method which is applied to research the structural groups of the 3rd class, the offered algorithm of the kinematic analysis allows to investigate mechanisms of the 4th class without need to rebuild the plan which was constructed in a uncertain scale, with the subsequent calculation of the real scale parameter of provided plotting of a graph.
Keywords: mechanism, kinematic research, velocity vector, plan of the velocity vectors.

Introduction. Improving of existing technology equipment of light industry and design of new machines connected with efficiency of existing analysis methods for structural group of planar mecha-

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nisms links, of which the last composed. The methods of investigation of dyads are the most effective today. Enough known the analyze methods of structural group to which four links enter. They form the 3rd class and 3rd order groups or 4th class and 2nd order groups, on the base of which you can structural synthesize the mechanisms of the relevant class.

On the one hand the structural group with six structural links have used or have significant prospects of application in machinery of technological equipment in light industry, on the other – the appropriateness (effectiveness) of their use is not theoretically justified because there is no known method for their kinematic and dynamic researches. This is due to the variety of structural groups that may be formed by six links and nine kinematic pairs.

Imperfection in methods of analysis of such structural groups is a factor of deterrence of their use in technological equipment.

Last decades significant number of publications devoted to the practical use of planar complex mechanisms, which class is at least four, a well as the questions of theoretical research of structural, kinematic and dynamic parameters.

Application of multilink structural groups in specific mechanisms is protected by patents for utility model [1...3]. The issue of a theoretical analysis of the upper class mechanisms, including mechanisms for light industry equipment, there are several works dedicated [5...9].

Tasks of kinematic research of complex flat mechanisms remain relevant because in each case, according to the class of mechanism, it is necessary to develop a new algorithm which combines several methods of kinematic analysis. Universal way to research of such complex mechanisms of fourth and higher classes does not exist at present time.

The aim of this research is to develop an algorithm kinetic research of velocities of the points that coincide with geometric centers kinematic pairs of structure group of the 4th class and 3rd order with movable close-cycle formed by connecting rod and two complex links.

Materials and Methods. The graphic-analytical method of a kinematic research will be used to achieve the goals of research. Development of an algorithm is based on provisions of the theory of mechanisms and engines about property of high classes mechanisms to change its class depending on another possible initial mechanism chosen conditionally which comes to structure of the conducted structural groups of the mechanism links and provisions of theoretical mechanics relatively to instantaneous center of velocity (ICV).

Let us consider the complex plane joint-lever mechanism of fourth class (Fig. 1).

The initial mechanism (links 0, 1) with Assur group of the 4th class and 3rd order, which includes the set of six links 2...7 ($n = 6$) with nine kinematic pairs of 5th class – A, B, C, D, E, L, K, M, N ($p_5 = 9$) – forming the mechanism of the 4th class with degree of freedom 1 by Chebyshev formula (mechanism with a driving crank):

$$W = 3n - 2p_5 - p_4 .$$

Structure formula of the complex mechanism that examines is

1st class (links 0, 1) → 4th class 3rd order (links 2…7).

The structural feature of the mechanism is the presence of variable form closed circuit, formed by four connecting rods BD, BC, DE, the EC, two of which – BD and EC – located opposite each other and have the form of complex links, forming with other parts three kinematic pairs, but rod 5 bears the four elements of kinematic pairs.

To perform the kinematic analysis of the mechanism using known methods of study of 3rd class complex mechanisms by graphic-analytical method is not possible. This is due to the fact that the connecting rod 2 which is directly connected to the crank 1 on the other side there are two rods 3, 4 attached, and their kinematic parameters and trajectory points are unknown.

Input parameters for kinematic study of the mechanism is the angular velocity of the crank 1 (ω_1 = const, s^{-1}) and the scale of the length (Kl, m/mm) of the mechanism kinematic scheme.

In [10] it was shown that the mechanisms of the upper classes have a structural property to change (decrease) the class provided by the replacement of primary mechanism for other possible first class mechanism.

If review the set of links 0, 7 as initial, the mechanism takes the form of 3rd class with structure formula

1st class (links 0, 7) → 2nd class 2nd order 1st type (links 5, 6) → 3rd class 3rd order (links 1…4).

If another possible initial mechanism is choose as a first class mechanism such as set of links 0, 6 then general view of the structure formula remains unchanged, and links 5, 7 will form the Assur group of the 2nd class in the formula.

Conventionally on the size and direction we set the angular velocity ω_7 of rocker 7 as a link, which, according to the formula of mechanism structure is the second conventionally possible leading link of the mechanism. On the plan of the mechanism velocity vector draw $\vec{Pl}$ vector of any length along perpendicular to the line ML. For definiteness the direction of angular velocity ω_7 we set clockwise. Compose a system of vector equations for determining of point *K* velocity:

$$\begin{Bmatrix} \vec{V}_K = \vec{V}_L + \vec{V}_{K;L} \\ \vec{V}_K = \vec{V}_N + \vec{V}_{K;N} \end{Bmatrix}. \qquad (1)$$

Let solve a system of equations and indicate $\vec{Pk}$ vector on the plan. In case of origin of *L*, *K*, *C*, *E* points to a complex link 5 and according to the theorem of similarity determine the position of points *e, c* and velocity vectors $\vec{V}_E$, $\vec{V}_C$ on the plane of velocity.

Note that to simplify the calculations, we can assume that the points *L*, *K*, *C*, *E* belonging to one link 5, which moves planar. The direction of the velocity vectors of points *K*, *L* is given by the kinematic scheme of the mechanism therefore vectors $\vec{V}_K$, $\vec{V}_L$ directed along perpendiculars to the NK and ML directions respectively.

Based on these conditions we determine the position of the P_5 — ICV of rod 5 as the point of intersection of continued axial lines of NK and ML links.

According to the theorem of determining the velocity points of the body, which has a planar movement we set on the velocity plan the length of one point velocity vector (for example, point L).

The velocity vectors of the other three points are proportional to the distance from them to the point P_5. Vectors of *L*, *K*, *C*, *E* points directed perpendicularly to the segments that connecting them with ICV of links 5. In fact, the instantaneous angular velocity of the connecting rod 5 around ICV of this link can be set conventionally.

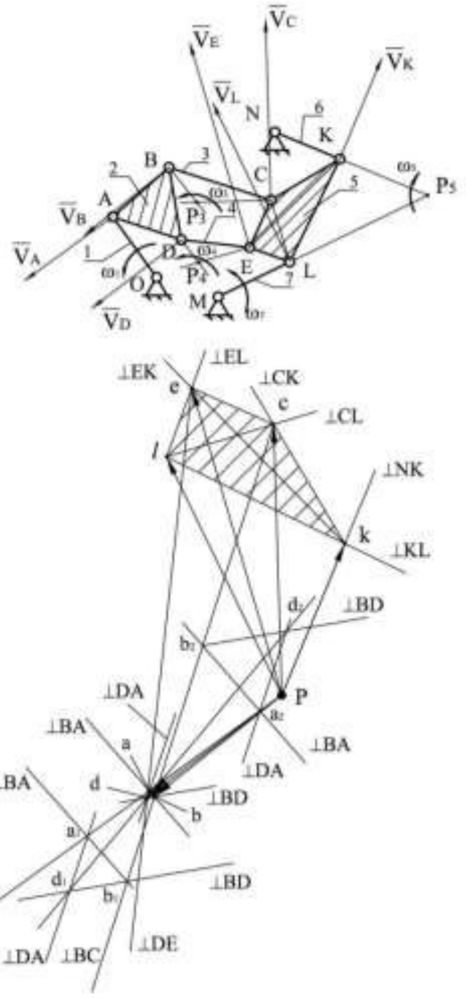

Fig. 1. Kinematic scheme and plan of the velocity vectors of the 4th class mechanism: 0 — riser, 1 — host link, 2…5 — rods, 6, 7 — rocker

A further solution is to choose the length of the velocity vector $\vec{V}_A$ of point *A* such that satisfies the condition of arbitrarily assumed value of the angular velocity of the connecting rod 5. Velocity $\vec{V}_A \perp OA$ directed toward the direction given angular velocity ω_1 of mechanism link 1 and line of possible real *a* point positions on velocity plan is the line that drawn through the pole *P* in a direction perpendicular to the crank *OA*.

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Set possible position of the point a_1 and solve a system of vector equations for determining the position of the other two points b_1 and d_1 on the plan:

$$\begin{Bmatrix} \vec{V}_B = \vec{V}_C + \vec{V}_{B;C}; \vec{V}_B = \vec{V}_A + \vec{V}_{B;A}; \\ \vec{V}_D = \vec{V}_A + \vec{V}_{D;A}; \vec{V}_D = \vec{V}_B + \vec{V}_{D;B}, \end{Bmatrix} \quad (2)$$

where relative velocities vectors are perpendicular to respective instantaneous radii rotation.

Analysis of the position of the d_1 allows stating that the position of point a_1 on the plan was not chosen correctly, because the received position of the d_1 does not match the vector equation

$$\vec{V}_D = \vec{V}_E + \vec{V}_{D;E}, \quad (3).$$

from which point d_1 must be on the line, which is drown through the point e perpendicularly to the segment DE.

Similarly, define the position of the d_2 for another arbitrarily selected point a_2 on the plan.

As in the previous case, the position of the a_2 defined incorrectly. The actual position of the point a is on crossing the line, based on the plan according to the vector equation (3) and lines d_1d_2. Under the system of vector equations (2) determine the actual position of the points b and d on the plan.

Results. The resulting plan of velocity is a graphic display of velocity vectors of linear point velocities of fourth class mechanism, constructed from the pole in an uncertain scale. In case of specified size of links and the angular velocity of the actual leading link to calculate the scale is easy.

Note, that unlike the known erroneous statements method which is applied to research the structural groups of the 3rd class, the offered algorithm of the kinematic analysis allows to investigate mechanisms of the 4th class without need to rebuild the plan which was constructed in a uncertain scale, with the subsequent calculation of the real scale parameter of provided plotting of a graph.

Conclusions. It was developed the algorithm for kinematic study of points velocities of the fourth class mechanism with the mobile closed circuit that formed by connecting rods and two complex links that is based on structural properties of higher class mechanisms to reduce class on the condition of other possible initial mechanism choice.

The proposed algorithm allows perform the kinematic analysis of complex mechanism on condition of graphic scale optimization of research constructions. In addition, the algorithm of kinematic analysis can be recommended for similar studies of complex planar mechanisms fourth and upper classes.

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