UDC 621.01

S. Koshel[1], PhD, Assoc. Prof.,
H. Koshel[2], PhD, Assoc. Prof.,
M. Zalyubovskii[2], DSc,
S. Popovichenko[3], PhD,
O. Koshel[1]
[1] Kyiv National University of Technology and Design, 2 Nemirovich-Danchenko Str., Kyiv, Ukraine, 01011, e-mail: sergey_koshel@ukr.net
[2] Open International University of Human Development "Ukraine", 23 Lvivska Str., Kyiv, Ukraine, 03115, e-mail: a_koshel@ukr.net
[3] Mykhailo Boychuk Kyiv State Academy of Decorative Applied Arts and Design, 2 Nemirovich-Danchenko Str., Kyiv, Ukraine, 01011, e-mail: sergeypopovichenko@gmail.com

STRUCTURAL ANALYSIS OF A THIRD-CLASS TEN-LINK MECHANISM WITH TWO COMPLEX LINKS

С. Кошель, Г. Кошель, М. Залюбовський, С. Поповіченко, О. Кошель. **Структурний аналіз десятиланкового механізму третього класу з двома складними ланками.** Основою технологічної машини є механізм, головною задачею якого є перетворення наперед відомого механічного руху рухомої ланки початкового механізму в необхідний для виконання технологічної операції рух веденої ланки, в певній точці якої розташований робочий орган машини. Якщо в структурі машини використовується складний механізм з двома та більше початковими механізмами, то рух кожної з ведучих ланок впливає на закон руху точки розташування робочого органу машини, що може призвести, наприклад, до його технологічної зупинки та знаходження в нерухомому стані певний проміжок часу, який обумовлений виконанням технологічної операції. Особливу увагу необхідно приділяти тим технологічним операціям де виконується операція «передачі» робочого матеріалу від одного до іншого робочого органу, які працюють синхронно. Надійне виконання такої технологічної операції можливо при зупинках одного з робочих органів або мінімізації їх відносних швидкостей. Наявність в структурі механізмів двох, трьох та більше ведучих ланок з одного боку дозволяє отримати позитивний результат для якісного виконання технологічної операції, а з іншого – значно ускладнює проведення задач аналізу та синтезу таких механічних систем. При дослідженні багатоланкових систем з декількома ведучим ланками виникає необхідність розробки та реалізації плану досліджень в кожному конкретному випадку таких складних механізмів з урахуванням їхніх структурних особливостей. Для механізму третього класу з двома складними ланками та трьома ведучими початковими механізмами розроблено та реалізовано план його структурного аналізу для визначення послідовності проведення подальших, наприклад, кінематичних досліджень. Десятиланковий механізм третього класу було структурно досліджено за допомогою розробленого поетапного аналізу структурно умовних механізмів з однією ведучою ланкою. Результати проведення аналізу в такій послідовності дозволили додатково визначити миттєві кінематичні параметри абсолютного руху ланки, рух якої обумовлений її кінематичним приєднанням до нерухомої ланки механізму, що остаточно дозволило виконати аналіз механізму третього класу з трьома ведучими ланками в спосіб притаманний для дослідження механізмів другого класу. Запропонований спосіб аналізу механізму третього класу може бути корисним для проведення аналогічних досліджень механічних систем вищого класу.
Ключові слова: механізм вищого класу, дослідження механізму, аналіз механізму, структурне дослідження, структурний аналіз, структурна група ланок, ступінь рухомості механізму

S. Koshel, H. Koshel, M. Zalyubovskyi, S. Popovichenko, O. Koshel. **Structural analysis of a third-class ten-link mechanism with two complex links.** The basis of a technological machine is a mechanism whose main task is to convert the predetermined mechanical motion of the moving link of the initial mechanism into the motion of the driven link required to perform a technological operation, with the working body of the machine positioned at a specific point of this link. If the machine structure includes a complex mechanism with two or more initial mechanisms, the motion of each driving link influences the motion law of the point where the working body is located. This can lead, for example, to its stoppage and remaining in a stationary state for a certain period determined by the execution of the technological operation. Particular attention should be paid to technological operations that involve the “transfer” of working material from one working body to another, which operate synchronously. Reliable execution of such an operation is possible either by stopping one of the working bodies or by minimizing their relative velocities. The presence of two, three, or more driving links in the mechanism structure, on the one hand, ensures a positive outcome for the high-quality execution of the technological operation, but on the other hand, significantly complicates the analysis and synthesis of such mechanical systems. When studying multi-link systems with multiple driving links, it becomes necessary to develop and implement a research plan for each specific case of such complex mechanisms, taking into account their structural features. For a third-class mechanism with two complex links and three driving initial mechanisms, a structural analysis plan has been developed and implemented to determine the sequence of further studies, such as kinematic analysis. The ten-link third-class mechanism was structurally analyzed using a step-by-step examination of conditional mechanisms with a single driving link in their structure. The results of this sequential analysis allowed for the additional determination of the instantaneous kinematic parameters of the absolute motion of a link, whose motion is conditioned by its kinematic connection to the fixed link of the mechanism. Ultimately, this made it possible to analyze the third-class mechanism with three driving links in a manner typical for the study of second-class mechanisms. The proposed method for analyzing third-class mechanisms may be useful for conducting similar studies on higher-class mechanical systems.
Keywords: higher-class mechanism, mechanism study, mechanism analysis, structural study, structural analysis, structural group of links, degree of mobility of the mechanism

Introduction

The basis of a technological machine is a mechanism whose main task is to convert the known mechanical movement of the moving link of the initial mechanism into the movement of the driven link, which is necessary for the technological operation, at a certain point of which the working body

DOI: 10.15276/opu.1.71.2025.03

 ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

of the machine is located. If the machine structure uses a complex mechanism with two or more starting mechanisms, the movement of each of the driving links affects the law of motion of the point where the working body of the machine is located. Particular attention should be paid to those technological operations where the operation of "transferring" the working material from one to another working body is performed, which work synchronously. Reliable performance of such a technological operation is possible with technological stops of one of the working bodies or minimisation of their relative speeds. On the one hand, the presence of two, three or more leading links in the structure of mechanisms allows obtaining a positive result for the qualitative performance of a technological operation, and on the other hand, it significantly complicates the tasks of analysis and synthesis of such mechanical systems. In the study of multi-link systems with several leading links, it becomes necessary to develop and implement a research plan in each case of such complex mechanisms, taking into account their structural features.

Analysis of key research and publications

Improving existing machines and designing new ones is associated with two groups of tasks that are solved in relation to the mechanisms of which they consist. Analysis tasks are performed for already created mechanisms used in machines, for which structural [1], kinematic [2], power [3], and special studies [4] are carried out. Synthesis problems are solved for mechanisms that do not yet exist when designing technological equipment, for example, at the stage of synthesising the structural scheme of a future mechanism [5] or after kinematic calculations have been performed [6]. Paper [7] provides an overview of existing methods of structural synthesis for complex planar mechanisms and provides the theoretical foundations for intelligent mechanism design, so paper [8], in which the authors try to identify common structural patterns of mechanisms, acquires new relevance. Paper [9] developed a synthesis method for planar multi-link mechanisms with eleven degrees of freedom. In [10], the authors analysed a complex flat mechanism of the fourth class using mathematical modelling, and performed a verification calculation using the graph-analytical method. A detailed analysis of complex mechanisms of a machine for machining parts is given in other works [11, 12]. The analysis of mechanisms with two parallel parking robot mechanisms was carried out in [13], and the study of mechanisms with three driving links is given in [14, 15].

The purpose of the study

The aim of the study is to carry out a structural analysis of a ten-link mechanism of the third class with two complex links and three initial mechanisms in its structure. The presence of three links whose movement is predetermined and a structural group of links of the third class with nine kinematic pairs and six links, two of which carry three elements of kinematic pairs, allows the structural analysis to be performed taking into account the provisions of the course "Theory of Mechanisms and Machines" on the property of mechanisms to change structurally depending on the selected conditionally different possible initial mechanism among the driven links of the mechanism under study.

Presentation of the main material

Let's perform a structural analysis of a ten-link mechanism of the third class with two complex links, the structural diagram of which is shown in Fig. 1. The flat mechanism consists of a body (link 0), simple links *1 – 6, 9* and two complex links *7, 8,* which are connected to each other by a rotating kinematic pair of the fifth class (pair "C"). Nine movable links, including three leading cranks (links *1, 2, 3*), which have rotational motion with predetermined laws of motion, and six driven links (links *4 – 9*), five of which move in plane parallel (connecting rods *4 – 8*) and one – translationally (slider *9*) relative to the vertical guides xx. The links of the mechanism form twelve kinematic pairs of the fifth class: eleven rotational and one translational. According to the formula for determining the mobility of the links (w) of a flat mechanism relative to a fixed body, we have $w = 3{\cdot}9 - 2{\cdot}12 = 3$. Three driving links *1, 2, 3* form three rotational pairs with the mechanism body (respectively, "O_1", "O_2", "O_3"), and on the other hand, the driven links, respectively, connecting rods 4, 5 and 6 of the structural group of links of the third class of the fourth order (links *4 – 9*), are connected to them by kinematic pairs "A_1", "A_2" and "A_3". In the structural group of driven links, the compound links 7 and 8 jointly form a rotating kinematic pair "C" and the other four rotating pairs "B", "E", "F", "D" are connected to three connecting rods *4, 5, 6* and slider *9*, respectively.

The presence of complex links *7, 8* in the structure of the third class mechanism with three driving links leads to the fact that the three driving cranks are connected to the driven structural group of links through kinematic chains of the "connecting rod – connecting rod" type. It is possible to draw up vector kinematic equations for the points that coincide with the centres of the internal kinematic pairs (pairs "B", "E", "F") of the structural group of links, but it is not possible to solve them, for example, using the graph-analytical method. When drawing up the kinematic equations for point "B", it is necessary to have the kinematic parameters of points "A_1" and D (or C) determined in advance. If point "A_1" belongs to the driving link 1 and its kinematic parameters are determined from the condition of rotation of the crank 1 around point "O_1" according to a predetermined law of motion, then with point "D" (or "C_2"), which belong to the connecting rod *7*, there are difficulties with determining their kinematic parameters.

Parameters at this stage of the analysis: on the other hand, point "D" coincides with the centre of the element of the rotational kinematic pair of the slider *9*, whose movement is not determined, and point "C" – with the center of the element of the rotational kinematic pair of the connecting rod *8*, whose kinematic parameters are unknown.

The structural study will be carried out according to a plan specially developed for such a complex mechanism in four stages. First, we will analyse how the movement of the driving link 1 affects the absolute movement of the slider *9*, for which we consider the structural diagram of the mechanism, where the driving links *2* and *3* are stationary (Fig. 2). The rotating pairs A_2 and A_3 are formed, respectively, by links *5* and 6 on the one hand and the housing on the other. For the conditional mechanism, we have one initial mechanism (links 0.1), to which a structural group of links of the third class (a set of links *4* – *9*) is attached.

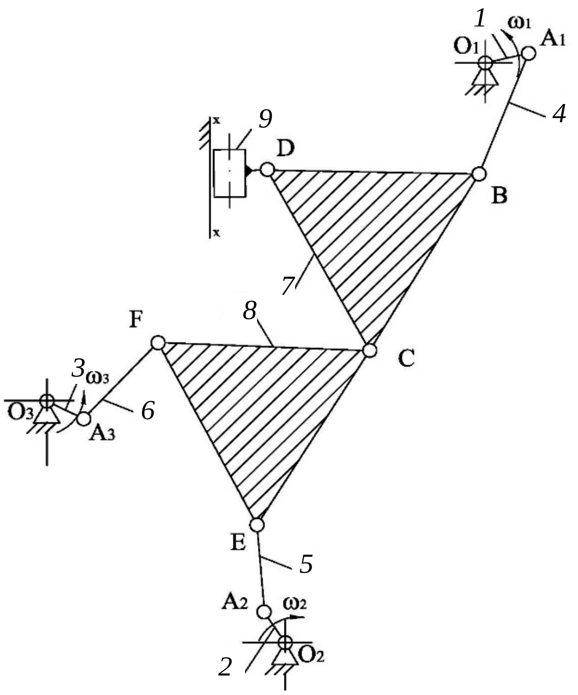

Fig. 1. Block diagram of a ten-link mechanism with three driving cranks *1*, 2, *3*

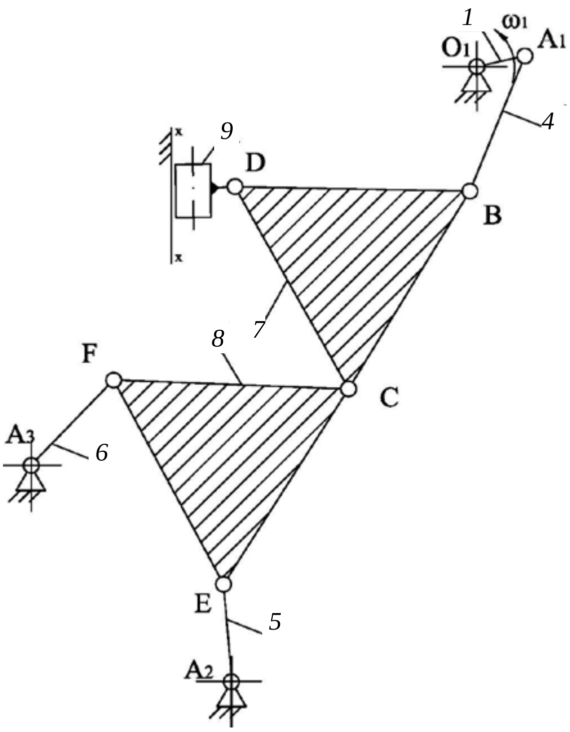

Fig. 2. Block diagram of a ten-link mechanism with a conditionally leading crank *1* ($\omega_1 = \text{const}$, $\omega_2 = \omega_3 = 0$, c^{-1})

At first glance, nothing has changed in terms of simplifying the study of such a third-class mechanism, but if we plan to conduct further analysis using the graph-analytic method, then it becomes possible to construct plans of velocities or accelerations of such a mechanism in a sequence determined by kinematic vector equations compiled for a conditionally different structurally possible initial mechanism [10]. If link 5 is chosen as a conditionally different possible leading link, then the structural formula of the mechanism's structure takes the form of a sequential connection to the initial mechanism (a set of links *0*, *5*) of three structural groups of links of the second class, respectively, sets of links *6*, *8*; *7*, *9* and *1*, *4* (Fig. 2), for which it is not difficult to conduct further research in a graphanalytical way.

 ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

The second stage of the study is related to the analysis of the influence of the movement of the driving link *2* on the absolute movement of the slider *9*. Conditionally stopping the driving cranks *1* and *3*, the structural diagram of such a mechanism takes the form shown in Fig. 3, and the formula of the structure consists of one initial mechanism (a set of links *0*, *2*) and a structural group of links of the third class (a set of links *4* and *5 – 9*).

It is possible to study such a conditional mechanism if we choose another leading link as another leading link, for example, link *9*, then the formula of the mechanism structure, according to which further analysis will be carried out (study of the absolute kinematic parameters of point "D"), takes the form of a second class mechanism, namely: the following structural groups of links of the second class are sequentially attached to the initial mechanism with a conditionally leading, slider *9*: sets of links *4*, *7*; *6*, *8* and *2*, *5*.

To implement the third stage of analysis, we assume that links *1*, *2* are fixed, and the structural diagram of the mechanism takes the form shown in Fig. 4. It is in this scheme that we can study the effect of the movement of the driving link *3* on the absolute movement of the slider *9* relative to the fixed vertical guide *xx*. The structural formula of the structure, which will determine the sequence of such an analysis, takes the form of a second-class mechanism. If, for example, link *4* is chosen as another leading link, the structural formula has the structure of a sequential connection of three structural groups of links of the second class (a set of links *7*, *9*; *5*, *8* and *3*, *6*) to a conditionally different possible initial mechanism with a moving link *4*.

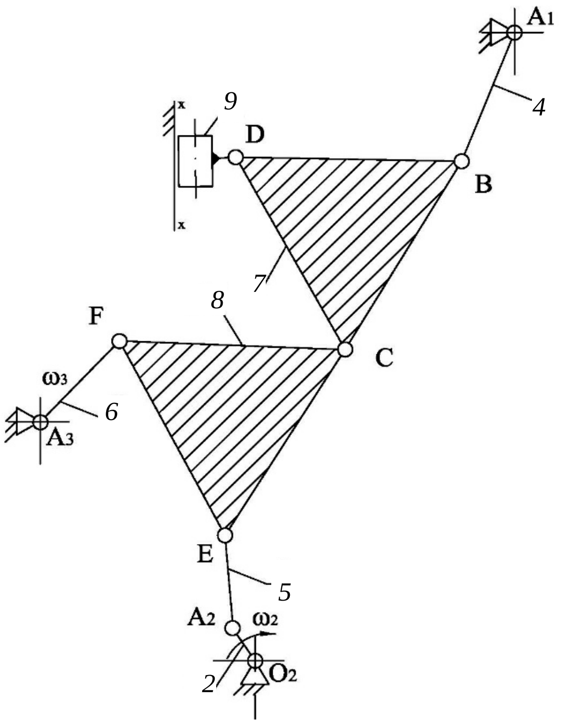

Fig. 3. Block diagram of a ten-link mechanism with a conditionally leading crank *2* ($\omega_2 = \text{const}$, $\omega_1 = \omega_3 = 0$, c^{-1})

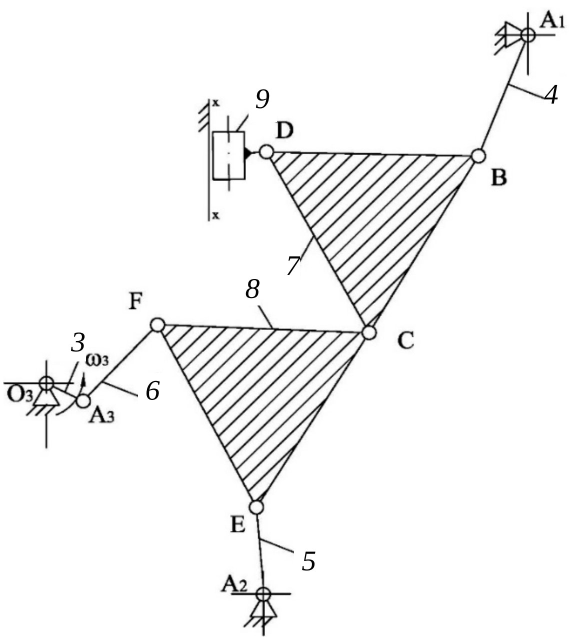

Fig. 4. Block diagram of a ten-link mechanism with a conditionally leading crank *3* ($\omega_3 = \text{const}$, $\omega_1 = \omega_2 = 0$, c^{-1})

We turn to the final fourth stage of the structural study of the third class mechanism with three driving links, which consists in analysing the mechanism, the structural diagram of which is shown in Fig. 1. After determining the influence of the movement of each of the driving links of the conventional mechanisms with one moving crank on the absolute translational movement of the slider *9* relative to the fixed guide, it became possible to calculate the instantaneously valid kinematic parameters of its absolute movement, provided that all three driving links of the mechanism move simultaneously. We find the algebraic sum of the corresponding kinematic parameters obtained during the implementation of the three previous stages of the analysis. After such calculations, for the final analysis of the third-class mechanism with two complex links and three initial mechanisms, we have as initial kinematic parameters four links: three cranks *1* , *2*, *3* and slider *9*. We conduct further studies of the third-class mechanism (Fig. 1) in the sequence caused by the sequentially parallel connection of conditional structural groups of links of the second class (first, the structural group of links *4*, *7*, and then groups of links *5*, *8* and *6*, *8*) to four links, the movement of which is determined for the instantaneous position of the mechanism.

Conclusions

For a third-class mechanism with two complex links and three leading initial mechanisms, a plan for its structural analysis was developed and implemented to determine the sequence of further, for example, kinematic studies. The ten-link mechanism of the third class was structurally investigated using the developed step-by-step analysis of structurally conditional mechanisms with one leading link. The results of the analysis in this sequence made it possible to additionally determine the instantaneous kinematic parameters of the absolute motion of the link, the movement of which is due to its kinematic connection to the fixed link of the mechanism, which finally allowed us to analyse the third class mechanism with three leading links in the manner inherent in the study of second class mechanisms. The proposed method of analysing a third-class mechanism can be useful for conducting similar studies of higher-class mechanical systems.

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Кошель Сергій Олександрович; Sergey Koshel, ORCID: https://orcid.org/0000-0001-7481-0186
Кошель Ганна Володимирівна; Hanna Koshel, ORCID: https://orcid.org/0000-0003-1862-1553
Залюбовський Марк Геннадійович; Mark Zalyubovskii, ORCID: https://orcid.org/0000-0001-6258-0088
Поповіченко Сергій Анатолійович; Serhii Popovichenko, ORCID: https://orcid.org/0000-0002-8971-9892
Кошель Олександр Сергійович; Oleksandr Koshel, ORCID:https://orcid.org/0009-0006-3788-9298

Received February 10, 2025
Accepted March 22, 2025