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STRUCTURAL SYNTHESIS AND GEOMETRY OF THE SPATIAL PARALLEL MANIPULATOR OF RCCC TYPE

Abstract

The spatial parallel manipulator of RCCC type is considered in this paper (R - revolute kinematic pair, C - cylindrical kinematic pair). This spatial parallel manipulator has been formed by connection of a link with working point of the anthropomorphic manipulator of RC type with three degrees of freedom with a frame by binary link of CC type. The right Cartesian coordinate system that fixed with each element of the kinematic pairs are used for describe the geometry of the considered parallel manipulator. Constant and variable parameters of the parallel manipulator structural scheme have been obtained. Constant parameters characterize the geometry of links, and variable parameters characterize the relative positions of the kinematic pairs elements.

Keywords: parallel manipulator, cylindrical and revolute kinematic pairs, structural synthesis.

Кілт сөздер: параллельді манипулятор, цилиндрлік және айналмалы кинематикалық жұптар, құры-лымдық синтез.

Ключевые слова: параллельный манипулятор, цилиндрические и вращательные кинематические пары, структурный синтез.

1 Introduction

There are many technological operations in industry where necessary a motion of the manipulator end-effector in one set trajectory. Autooperators or fixed-sequence manipulators with one degree of freedom are used to perform these operations. Autooperators can not readjust to changing technological operation. However, they are reliable devices having a simple control system instead of manipulators with many degrees of freedom. Therefore, it is advisable to use autooperators instead of manipulators with many degrees of freedom in automatic machines working on hard-coded program.

Autooperators reproduce the given laws of end-effectors motions in definite structural schemes and geometrical parameters of links. This paper presents the methods of structural synthesis and determination of the geometrical parameters of links of the spatial parallel manipulator of RCCC type. Structural scheme and geometrical parameters of links of the parallel manipulator of RCCC type have been used for its kinematic analysis [1].

2 Structural synthesis of the spatial parallel manipulator of RCCC type

According to the principle of parallel manipulators formation [2, 3] they are formed from the executive and closing kinematic chains. Kinematic chains with many degrees-of-freedom reproducing the given laws of end-effectors are called the executive kinematic chains. Kinematic chains connecting the executive kinematic chains and a frame called closing kinematic chains.

Anthropomorphic manipulators with three degrees-of-freedom reproducing the given laws of end-effectors are the executive kinematic chains. The anthropomorphic manipulator *ABP* of RC type (Fig. 1) is the simplest positioning anthropomorphic manipulator, which reproduces the following given laws

$$V_P = V_P(t),\ W_P = W_P(t) \tag{1}$$

or *N* discrete position

$$U_{P_i} = U_P(t_i),\ V_{P_i} = V_P(t_i),\ W_{P_i} = W_P(t_i),\ (i = 1,2,...,N) \tag{2}$$

of the working (output) point *P* in the absolute coordinate system $OU_OV_OW_O$.

Degree of freedom of a spatial parallel manipulator can be defined by Somov-Malyshev formula [4]:

$$W = 6n - \sum kp_k - \delta\ , \tag{3}$$

where *n* - number of mobile links, p_k - number of kinematic pairs of *k*-th class, δ - number of local mobility. Class of kinematic pair is determined by the number of restruction of motion kinematic pair elements. For anthropomorphic manipulator *ABP* of RC type: $n = 2$, $p_4 = 1$ (cylindrical kinematic pair *B*), $p_5 = 1$ (revolute kinematic pair *A*), $\delta = 0$. Then we get

$$W = 6 \cdot 2 - 1 \cdot 5 - 1 \cdot 4 = 3\,.$$

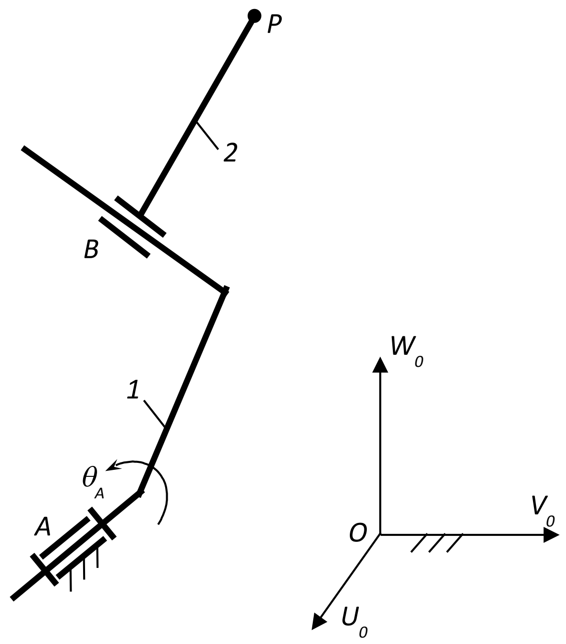

Figure 1 – The anthropomorphic manipulator *ABP* of RC type

If we connect the link *2* of the anthropomorphic manipulator *ABP* of RC type with a frame by closing kinematic chain, in this case, the binary link *CD* of CC type, which has two negative degrees of freedom, we get the spatial parallel manipulator of RCCC type with one degree of freedom (Fig. 2). A link with two kinematic pairs is called a binary link. The degree of freedom of the binary link of CC type has been defined by formula (3), where $n = 1$, $p_4 = 2$, $\delta = 0$. Then we get $W = 6 \cdot 1 - 2 \cdot 4 = -2$. Input (active) kinematic pair of this parallel manipulator is a revolute kinematic pair *A*.

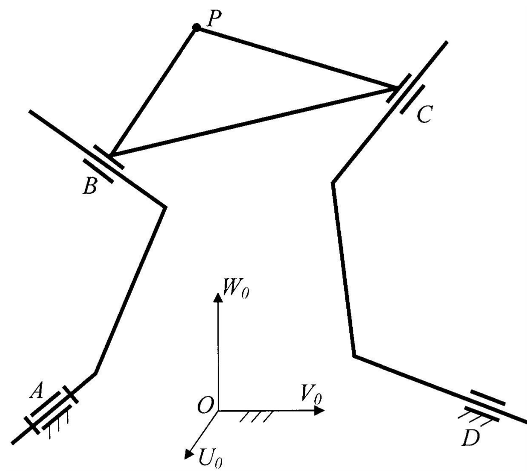

Figure2 – The spatial parallel manipulator RCCC type

3 Geometry of the spatial parallel manipulator of RCCC type

Two right Cartesian coordinate systems *UWV* and *XYZ* are fixed with each element of kinematic pair of the considered parallel manipulator for describe its geometry. The axes *W* and *Z* are directed along the axes of rotation or translation of the kinematic pair, and the axes *U* and *X* are directed along the shortest distance between the axes *W* and *Z*. The axes *V* and *Y* are complemented of the right Cartesian coordinate systems *UVW* and *XYZ*. The transformation matrix between the coordinate systems $U_j V_j W_j$ and $X_k Y_k Z_k$ (Fig. 3) that are fixed to the ends of the binary link *jk* has the following form

$$\mathbf{T}_{jk} = \mathbf{T}_{jk}(a_{jk}, b_{jk}, c_{jk}, \alpha_{jk}, \beta_{jk}, \gamma_{jk}) = \begin{bmatrix} t_{11} & t_{12} & t_{13} & t_{14} \\ t_{21} & t_{22} & t_{23} & t_{24} \\ t_{31} & t_{32} & t_{33} & t_{34} \\ t_{41} & t_{42} & t_{43} & t_{44} \end{bmatrix} = \left[\begin{array}{c|c} 1 & 0 \\ \hline {}^{j}T_k & {}^{j}\mathbf{R}_k \end{array}\right], \tag{4}$$

where

$$t_{11} = 1,\ t_{12} = t_{13} = t_{14} = 0,$$

$$t_{21} = a_{jk} \cdot \cos\gamma_{jk} + b_{jk} \cdot \sin\gamma_{jk} \cdot \sin\alpha_{jk},$$

$$t_{22} = \cos\gamma_{jk} \cdot \cos\beta_{jk} - \sin\gamma_{jk} \cdot \cos\alpha_{jk} \cdot \sin\beta_{jk},$$

$$t_{23} = -\cos\gamma_{jk} \cdot \sin\beta_{jk} - \sin\gamma_{jk} \cdot \cos\alpha_{jk} \cdot \cos\beta_{jk},\ t_{24} = \sin\gamma_{jk} \cdot \sin\alpha_{jk},$$

$$t_{31} = a_{jk} \cdot \sin\gamma_{jk} - b_{jk} \cdot \cos\gamma_{jk} \cdot \sin\alpha_{jk},$$

$$t_{32} = \sin\gamma_{jk} \cdot \cos\beta_{jk} + \cos\gamma_{jk} \cdot \cos\alpha_{jk} \cdot \sin\beta_{jk},$$

$$t_{33} = \cos\gamma_{jk} \cdot \cos\alpha_{jk} \cdot \cos\beta_{jk} - \sin\gamma_{jk} \cdot \sin\beta_{jk},\ t_{34} = -\cos\gamma_{jk} \cdot \sin\alpha_{jk},$$

$$t_{41} = c_{jk} + b_{jk} \cdot \cos\alpha_{jk},\ t_{42} = \sin\alpha_{jk} \cdot \sin\beta_{jk},$$

$$t_{43} = \sin\alpha_{jk} \cdot \cos\beta_{jk},\ t_{44} = \cos\alpha_{jk},$$

i.e. a relative position of the two coordinate systems $U_j V_j W_j$ and $X_k Y_k Z_k$ are defined by the following six parameters: a_{jk} - a distance from axis W_j to axis Z_k which is measured along the direction of t_{jk}; t_{jk} – a common perpendicular between axes W_j and Z_k; α_{jk} - an angle between positive directions of axes W_j and Z_k which is measured counter clockwise relatively to positive direction of t_{jk}; b_{jk} - a distance from direction of t_{jk} to direction of the axis X_k which is measured along positive direction of an axis Z_k; β_{jk} - an angle between positive directions of t_{jk} and axis X_k which is measured counter clockwise relatively to positive direction of axis Z_k; c_{jk} - a distance from direction of an axis U_j to direction of t_{jk} which is measured along positive direction of an axis W_j; γ_{jk} - an angle between positive directions of axis U_j and t_{jk} which is measured counter clockwise relatively to positive direction of an axis W_j.

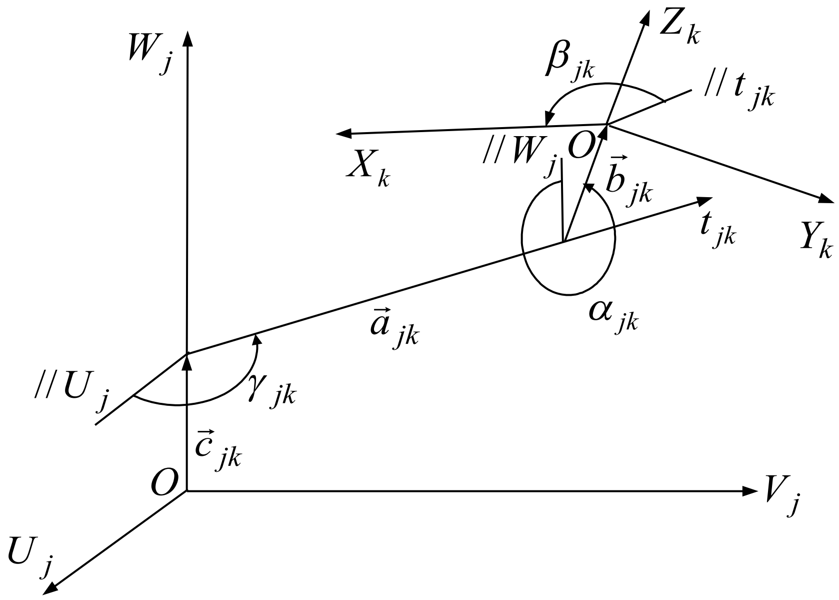

Figure 3 – The coordinate systems $U_jV_jW_j$ and $X_kY_kZ_k$

The chosen coordinate systems and the parameters of the spatial parallel manipulator of RCCC type are shown in Fig. 4. Absolute coordinate system is indicated $U_0V_0W_0$. As can be seen from Fig. 4, the binary link *AB* of RC type has constant parameters a_{AB}, α_{AB}, c_{AB}; the binary link *BC* of CC has constant parameters a_{BC}, α_{BC}; the binary link *CD* of CC has constant parameters a_{CD}, α_{CD}; the revolute kinematic pair has variable parameter $\theta_A = \gamma_{AB}$; the cylindrical kinematic pairs *B*, *C* and *D* have variables parameters $s_{BC} = c_{BC}$, $\theta_B = \gamma_{BC}$, $s_C = c_{CD}$, $\theta_C = \gamma_{CD}$ и $s_D = c$, $\theta_D = \gamma_{DC}$, accordingly. The revolute kinematic pair *A* is an active kinematic pair, and the cylindrical kinematic pairs *B*, *C*, and *D* are passive kinematic pairs. Hence, the variable parameters θ_A is the generalized coordinate, and the variable parameters s_B, θ_B, s_C, θ_C, s_D, θ_D, will be defined from direct kinematics of the considered parallel manipulator. In addition to these constant and variable parameters the considered parallel manipulator has the following groups of constant parameters a_{OA}, α_{OA}, c_{OA}, γ_{OA} and a_{OD}, α_{OD}, c_{OD}, γ_{OD} determining the position of the coordinate systems $X_A Y_A Z_A$ и $X_D Y_D Z_D$ that are fixed with the immovable elements of the kinematic pairs *A* and *D* in the absolute coordinate system $U_0 V_0 W_0$. Then the symbolic equation of considered parallel manipulator has a view

$$\mathbf{F}_{OA}\begin{vmatrix} a_{OA} \\ \alpha_{OA} \\ 0 \\ 0 \\ c_{OA} \\ \gamma_{OA} \end{vmatrix} \cdot \mathbf{P}_A^R(\theta_A) \cdot \mathbf{G}_{AB}^{RC}\begin{vmatrix} a_{AB} \\ \alpha_{AB} \\ 0 \\ 0 \\ c_{AB} \\ 0 \end{vmatrix} \cdot \mathbf{P}_B^C(s_B, \theta_B) \cdot \mathbf{G}_{BC}^{CC}\begin{vmatrix} a_{BC} \\ \alpha_{BC} \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} \cdot$$

$$\cdot \mathbf{P}_C(s_C, \theta_C) \cdot \mathbf{G}_{CD}^{CC}\begin{vmatrix} a_{CD} \\ \alpha_{CD} \\ b_{CD} \\ 0 \\ 0 \\ 0 \end{vmatrix} \cdot \mathbf{P}_D^{Ц}(s_D, \theta_D) \cdot \mathbf{F}_{OD}^{-1}\begin{vmatrix} a_{OD} \\ \alpha_{OD} \\ 0 \\ 0 \\ c_{OD} \\ \gamma_{OD} \end{vmatrix} = \mathbf{E}, \qquad (5)$$

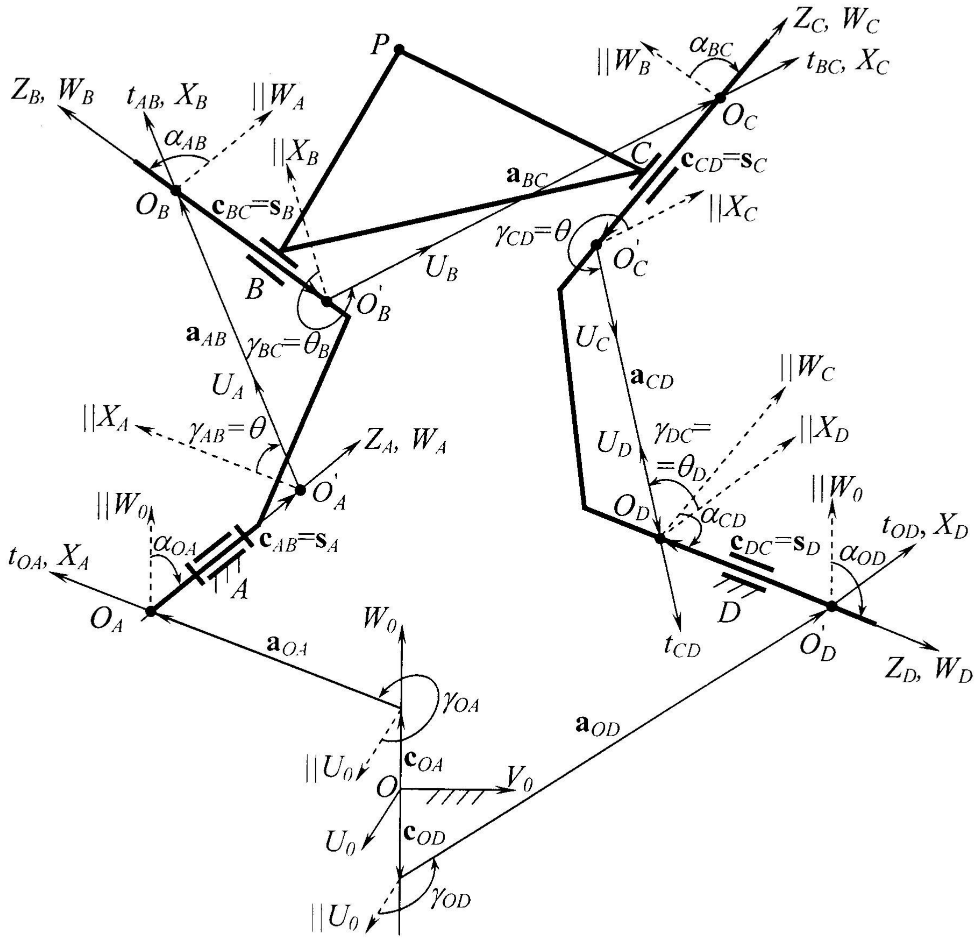

Figure 4 – The coordinate systems and parameters of the RCCC PM

where $\mathbf{F}_{OA}$ and $\mathbf{F}_{OD}$ - the transformation matrixes from the coordinate system $U_0V_0W_0$ to the coordinate systems $X_AY_AZ_A$ and $X_DY_DZ_D$ accordingly; **E** – unit matrix; $\mathbf{P}_A^R$, $\mathbf{P}_B^C$, $\mathbf{P}_C^C$, and $\mathbf{P}_D^C$ - the matrixes of the kinematic pairs *A*, *B*, *C*, and *D*, where the variable parameters characterizing the relative positions of the elements of the kinematic pairs are shown in the parenthesis; $\mathbf{G}_{AB}^{RC}$, $\mathbf{G}_{BC}^{CC}$, $\mathbf{G}_{CD}^{CC}$ - the matrixes of the binary links *AB*, *BC*, *CD* of RC, CC, CC types, where the constant parameters characterizing the geometry of the binary links are shown in the vertical columns.

We obtain the matrix of the kinematic pairs and binary links after supplying the variable and constant parameters of the matrixes of the kinematic pairs and binary links in the matrix $\mathbf{T}_{jk}$ (4). Note that, the symbolic equation (5) is the matrix equation for closure of loop for the considered parallel manipulator which is used for the kinematic and dynamic analysis.

The matrixes of the kinematic pairs have the following views

- the revolute kinematic pair *A*

$$\mathbf{P}_A^R(\theta_A)=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & \cos\theta_A & -\sin\theta_A & 0\\ 0 & \sin\theta_A & \cos\theta_A & 0\\ 0 & 0 & 0 & 1\end{bmatrix}, \qquad (6)$$

- the cylindrical kinematic pairs *B*, *C*, and *D*

$$\mathbf{P}_B^C(s_p,\theta_A)=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & \cos\theta_p & -\sin\theta_p & 0\\ 0 & \sin\theta_p & \cos\theta_p & 0\\ s_P & 0 & 0 & 1\end{bmatrix}, \left(p=B,\,C,\,D\right). \qquad (7)$$

The matrixes of the binary links have the following views:

- the binary link *AB* of RC type

$$\mathbf{G}_{AB}^{RC}(a_{AB},\alpha_{AB},c_{AB})=\begin{bmatrix}1 & 0 & 0 & 0\\ a_{AB} & 1 & 0 & 0\\ 0 & 0 & \cos\alpha_{AB} & \text{-}\sin\theta_{AB}\\ c_{AB} & 0 & \sin\theta_{AB} & \cos\alpha_{AB}\end{bmatrix}, \qquad (8)$$

- the binary links *BC* and *CD* of CC type

$$\mathbf{G}_{jk}^{CC}(a_{jk},\alpha_{jk})=\begin{bmatrix}1 & 0 & 0 & 0\\ a_{jk} & 1 & 0 & 0\\ 0 & 0 & \cos\alpha_{jk} & \text{-}\sin\alpha_{jk}\\ 0 & 0 & \sin\alpha_{jk} & \cos\alpha_{jk}\end{bmatrix}, \left(j=A,B;\;\; k=B,C\right). \qquad (9)$$

4 Conclusion

The structural scheme of the spatial parallel manipulator of RCCC type is synthesized. The structural scheme of this parallel manipulator is formed by connection of the link of the spatial anthropomorphic manipulator of RC type with a frame by the binary link of CC types. The matrixes of the binary link of RC and CC types and the revolute and cylindrical kinematic pairs are composed. The elements of the matrixes of the binary links of RC and CC types are constant, and they characterize the geometry of the binary links. The elements of the revolute and cylindrical kinematic pairs are variable, and they characterize the relative positions of their elements.

ЛИТЕРАТУРА

1. Zh.Zh. Baigunchekov, M.B. Izmambetov, and N.Zh. Baigunchekov. Kinematics of the Spatial Parallel Manipulator of RCCC Type. *World Congress on Engineering WCE2013,* London, UK, 3-5 July, 2013 (it is presented).

2. Zh.Zh. Baigunchekov, S.U. Joldasbekov. Modular Synthesis of Spatial Manipulating Devices of High Classes. *Proceedings of the Twelfth International Conference on CAD/CAM Robotics and Factories of the Future. Middlesex University*, London, England, 14-16 August, 1996, pp. 685-690.

3. Zh.Zh. Baigunchekov, Raj Gill, Antony S. White, N.Zh. Baigunchekov. The Basis of Structural and Parametric Synthesis of The Parallel Manipulators with Functionally Independent Drives (Part I and Part II). *Proceedings of the International Conference on Gearing, Transmissions, and Mechanical Systems*, Nottingham Trent University, UK, 3-6 July, 2000, pp.1-19.

4. I.I. Artobolevskiy. Theory of Mechanisms and Machines. Moscow, 2003, 538 p.

REFERENCES

1. Zh.Zh. Baigunchekov, M.B. Izmambetov, and N.Zh. Baigunchekov. Kinematics of the Spatial Parallel Manipulator of RCCC Type. *World Congress on Engineering WCE2013,* London, UK, 3-5 July, 2013 (it is presented).

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Резюме

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АЦЦЦ ТИПТІ КЕҢІСТІКТІК ПАРАЛЛЕЛЬДІ МАНИПУЛЯТОРДЫҢ

ҚҰРЫЛЫМДЫҚ СИНТЕЗІ МЕН ГЕОМЕТРИЯСЫ

Бұл мақалада АЦЦЦ (А – айналмалы кинематикалық жұп, Ц – цилиндрлік кинематикалық жұп) типті кеңістіктік параллельді манипулятор қарастырылады. Бұл кеңістіктік параллельді манипулятор үш еркіндік дәрежелі АЦ типті антропоморфты манипулятордың атқарушы буынын ЦЦ типті бинарлы буын арқылы тағанға жалғау негізінде құрастырылған. Қарастырылып отырған параллельді манипулятордың геометриясын сипаттау үшін кинематикалық жұптардың әрбір элементіне бекітілген оң декарттық координаталар жүйесі қолданылады. Параллельді манипулятор құрылымдық сұлбасының тұрақты және айнымалы параметрлері айқындалды. Тұрақты параметрлер буындар геометриясын сипаттаса, айнымалы параметрлер кинематикалық жұптар элементтерінің өзара орналасуларын сипаттайды.

Кілт сөздер: параллельді манипулятор, цилиндрлік және айналмалы кинематикалық жұптар, құрылымдық синтез.

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СТРУКТУРНЫЙ СИНТЕЗ И ГЕОМЕТРИЯ ПРОСТРАНСТВЕННОГО

ПАРАЛЛЕЛЬНОГО МАНИПУЛЯТОРА ВЦЦЦ ТИПА

В данной статье рассматривается пространственный параллельный манипулятор ВЦЦЦ типа (В – вращательная кинематическая пара, Ц – цилиндрическая кинематическая пара). Данный параллельный манипулятор сформирован соединением рабочего звена антропоморфного манипулятора ВЦ типа с тремя степенями свободы со стойкой посредством бинарного звена ЦЦ типа. Для описания геометрии рассматриваемого параллельного манипулятора используются правые декартовы системы координат, жестко связанные с каждым элементом кинематических пар. Получены постоянные и переменные параметры структурной схемы параллельного манипулятора. Постоянные параметры характеризуют геометрию звеньев, а переменные параметры характеризуют относительные положения элементов кинематических пар.

Ключевые слова: параллельный манипулятор, цилиндрические и вращательные кинематические пары, структурный синтез.

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1 Introduction

There are many technological operations in industry where necessary a motion of the manipulator end-effector in one set trajectory. Autooperators or fixed-sequence manipulators with one degree of freedom are used to perform these operations. Autooperators can not readjust to changing technological operation. However, they are reliable devices having a simple control system instead of manipulators with many degrees of freedom. Therefore, it is advisable to use autooperators instead of manipulators with many degrees of freedom in automatic machines working on hard-coded program.

Autooperators reproduce the given laws of end-effectors motions in definite structural schemes and geometrical parameters of links. This paper presents the methods of structural synthesis and determination of the geometrical parameters of links of the spatial parallel manipulator of RCCC type. Structural scheme and geometrical parameters of links of the parallel manipulator of RCCC type have been used for its kinematic analysis [1].

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or N discrete position

$$U_{P_i} = U_P(t_i),\ V_{P_i} = V_P(t_i),\ W_{P_i} = W_P(t_i),\ (i = 1,2,\dots,N) \quad (2)$$

of the working (output) point P in the absolute coordinate system OUOVOWO.

Degree of freedom of a spatial parallel manipulator can be defined by Somov-Malyshev formula [4]:

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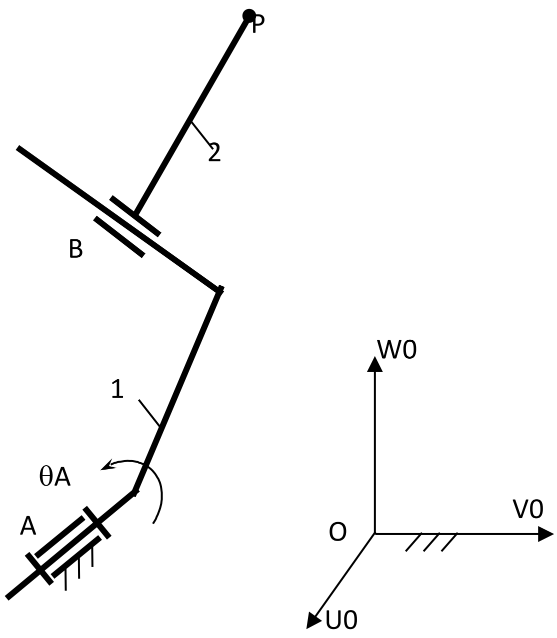

Figure 1 – The anthropomorphic manipulator ABP of RC type

If we connect the link 2 of the anthropomorphic manipulator ABP of RC type with a frame by closing kinematic chain, in this case, the binary link CD of CC type, which has two negative degrees of freedom, we get the spatial parallel manipulator of RCCC type with one degree of freedom (Fig. 2). A link with two kinematic pairs is called a binary link. The degree of freedom of the binary link of CC type has been defined by formula (3), where $n=1$, $p_4=2$, $\delta=0$. Then we get $W=6\cdot 1-2\cdot 4=-2$. Input (active) kinematic pair of this parallel manipulator is a revolute kinematic pair A.

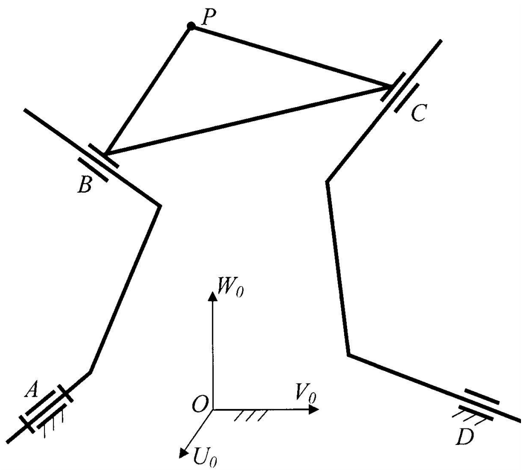

Figure2 – The spatial parallel manipulator RCCC type

3 Geometry of the spatial parallel manipulator of RCCC type

Two right Cartesian coordinate systems UWV and XYZ are fixed with each element of kinematic pair of the considered parallel manipulator for describe its geometry. The axes W and Z are directed along the axes of rotation or translation of the kinematic pair, and the axes U and X are directed along the shortest distance between the axes W and Z. The axes V and Y are complemented of the right Cartesian coordinate systems UVW and XYZ. The transformation matrix between the coordinate systems $U_jV_jW_j$ and $X_kY_kZ_k$ (Fig. 3) that are fixed to the ends of the binary link jk has the following form

$$\mathbf{T}_{jk} = \mathbf{T}_{jk}(a_{jk}, b_{jk}, c_{jk}, \alpha_{jk}, \beta_{jk}, \gamma_{jk}) = \begin{bmatrix} t_{11} & t_{12} & t_{13} & t_{14} \\ t_{21} & t_{22} & t_{23} & t_{24} \\ t_{31} & t_{32} & t_{33} & t_{34} \\ t_{41} & t_{42} & t_{43} & t_{44} \end{bmatrix} = \left[\begin{array}{c|c} 1 & 0 \\ \hline {}^{j}T_k & {}^{j}\mathbf{R}_k \end{array}\right], \qquad (4)$$

where

$$t_{11} = 1,\ t_{12} = t_{13} = t_{14} = 0,$$

$$t_{21} = a_{jk} \cdot \cos\gamma_{jk} + b_{jk} \cdot \sin\gamma_{jk} \cdot \sin\alpha_{jk},$$

$$t_{22} = \cos\gamma_{jk} \cdot \cos\beta_{jk} - \sin\gamma_{jk} \cdot \cos\alpha_{jk} \cdot \sin\beta_{jk},$$

$$t_{23} = -\cos\gamma_{jk} \cdot \sin\beta_{jk} - \sin\gamma_{jk} \cdot \cos\alpha_{jk} \cdot \cos\beta_{jk},\ t_{24} = \sin\gamma_{jk} \cdot \sin\alpha_{jk},$$

$$t_{31} = a_{jk} \cdot \sin\gamma_{jk} - b_{jk} \cdot \cos\gamma_{jk} \cdot \sin\alpha_{jk},$$

$$t_{32} = \sin\gamma_{jk} \cdot \cos\beta_{jk} + \cos\gamma_{jk} \cdot \cos\alpha_{jk} \cdot \sin\beta_{jk},$$

$$t_{33} = \cos\gamma_{jk} \cdot \cos\alpha_{jk} \cdot \cos\beta_{jk} - \sin\gamma_{jk} \cdot \sin\beta_{jk},\ t_{34} = -\cos\gamma_{jk} \cdot \sin\alpha_{jk},$$

$$t_{41} = c_{jk} + b_{jk} \cdot \cos\alpha_{jk},\ t_{42} = \sin\alpha_{jk} \cdot \sin\beta_{jk},$$

$$t_{43} = \sin\alpha_{jk} \cdot \cos\beta_{jk},\ t_{44} = \cos\alpha_{jk},$$

i.e. a relative position of the two coordinate systems $U_jV_jW_j$ and $X_kY_kZ_k$ are defined by the following six parameters: a_{jk} - a distance from axis W_j to axis Z_k which is measured along the direction of t_{jk}; t_{jk} – a common perpendicular between axes W_j and Z_k; α_{jk} - an angle between positive directions of axes W_j and Z_k which is measured counter clockwise relatively to positive direction of t_{jk}; b_{jk} - a distance from direction of t_{jk} to direction of the axis X_k which is measured along positive direction of an axis Z_k; β_{jk} - an angle between positive directions of t_{jk} and axis X_k which is measured counter clockwise relatively to positive direction of axis Z_k; c_{jk} - a distance from direction of an axis U_j to direction of t_{jk} which is measured along positive direction of an axis W_j; γ_{jk} - an angle between positive directions of axis U_j and t_{jk} which is measured counter clockwise relatively to positive direction of an axis W_j.

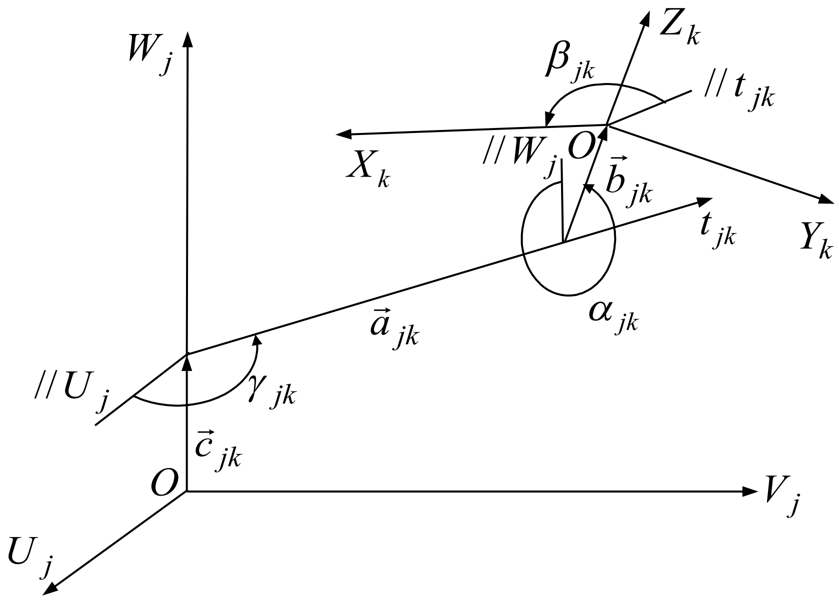

Figure 3 – The coordinate systems $U_jV_jW_j$ and $X_kY_kZ_k$

The chosen coordinate systems and the parameters of the spatial parallel manipulator of RCCC type are shown in Fig. 4. Absolute coordinate system is indicated $U_0V_0W_0$. As can be seen from Fig. 4, the binary link AB of RC type has constant parameters a_{AB}, α_{AB}, c_{AB}; the binary link BC of CC has constant parameters a_{BC}, α_{BC}; the binary link CD of CC has constant parameters a_{CD}, α_{CD}; the revolute kinematic pair has variable parameter $\theta_A = \gamma_{AB}$; the cylindrical kinematic pairs B, C and D have variables parameters $s_{BC} = c_{BC}$, $\theta_B = \gamma_{BC}$,

$s_C = c_{CD}$, $\theta_C = \gamma_{CD}$ и $s_D = c$, $\theta_D = \gamma_{DC}$, accordingly. The revolute kinematic pair A is an active kinematic pair, and the cylindrical kinematic pairs B, C, and D are passive kinematic pairs. Hence, the variable parameters θ_A is the generalized coordinate, and the variable parameters s_B, θ_B, s_C, θ_C, s_D, θ_D, will be defined from direct kinematics of the considered parallel manipulator. In addition to these constant and variable parameters the considered parallel manipulator has the following groups of constant parameters a_{OA}, α_{OA}, c_{OA}, γ_{OA} and a_{OD}, α_{OD}, c_{OD}, γ_{OD} determining the position of the coordinate systems $X_A Y_A Z_A$ и $X_D Y_D Z_D$ that are fixed with the immovable elements of the kinematic pairs A and D in the absolute coordinate system $U_0 V_0 W_0$. Then the symbolic equation of considered parallel manipulator has a view

$$\mathbf{F}_{OA}\begin{vmatrix} a_{OA} \\ \alpha_{OA} \\ 0 \\ 0 \\ c_{OA} \\ \gamma_{OA} \end{vmatrix} \cdot \mathbf{P}_A^R(\theta_A) \cdot \mathbf{G}_{AB}^{RC}\begin{vmatrix} a_{AB} \\ \alpha_{AB} \\ 0 \\ 0 \\ c_{AB} \\ 0 \end{vmatrix} \cdot \mathbf{P}_B^C(s_B, \theta_B) \cdot \mathbf{G}_{BC}^{CC}\begin{vmatrix} a_{BC} \\ \alpha_{BC} \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} \cdot$$

$$\cdot \mathbf{P}_C(s_C, \theta_C) \cdot \mathbf{G}_{CD}^{CC}\begin{vmatrix} a_{CD} \\ \alpha_{CD} \\ b_{CD} \\ 0 \\ 0 \\ 0 \end{vmatrix} \cdot \mathbf{P}_D^{Ц}(s_D, \theta_D) \cdot \mathbf{F}_{OD}^{-1}\begin{vmatrix} a_{OD} \\ \alpha_{OD} \\ 0 \\ 0 \\ c_{OD} \\ \gamma_{OD} \end{vmatrix} = \mathbf{E}, \tag{5}$$

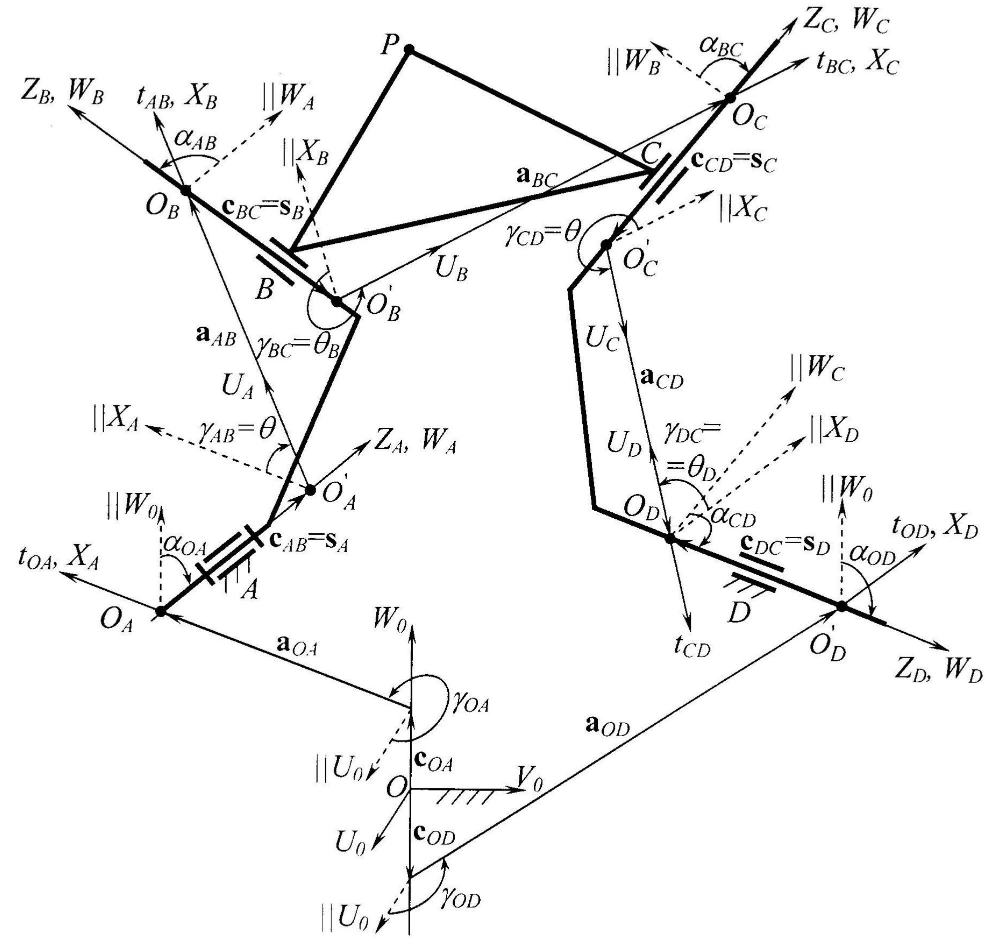

Figure 4 – The coordinate systems and parameters of the RCCC PM

where $\mathbf{F}_{OA}$ and $\mathbf{F}_{OD}$ - the transformation matrixes from the coordinate system $U_0V_0W_0$ to the coordinate systems $X_AY_AZ_A$ and $X_DY_DZ_D$ accordingly; E – unit matrix; $\mathbf{P}_A^R$, $\mathbf{P}_B^C$, $\mathbf{P}_C^C$, and $\mathbf{P}_D^C$ - the matrixes of the kinematic pairs A, B, C, and D, where the variable parameters characterizing the relative positions of the elements of the kinematic pairs are shown in the parenthesis; $\mathbf{G}_{AB}^{RC}$, $\mathbf{G}_{BC}^{CC}$, $\mathbf{G}_{CD}^{CC}$ - the matrixes of the binary links AB, BC, CD of RC, CC, CC types, where the constant parameters characterizing the geometry of the binary links are shown in the vertical columns.

We obtain the matrix of the kinematic pairs and binary links after supplying the variable and constant parameters of the matrixes of the kinematic pairs and binary links in the matrix $\mathbf{T}_{jk}$ (4). Note that, the symbolic equation (5) is the matrix equation for closure of loop for the considered parallel manipulator which is used for the kinematic and dynamic analysis.

The matrixes of the kinematic pairs have the following views

- the revolute kinematic pair A

$$\mathbf{P}_A^R(\theta_A)=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & \cos\theta_A & -\sin\theta_A & 0\\ 0 & \sin\theta_A & \cos\theta_A & 0\\ 0 & 0 & 0 & 1\end{bmatrix}, \qquad (6)$$

- the cylindrical kinematic pairs B, C, and D

$$\mathbf{P}_B^C(s_p,\theta_A)=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & \cos\theta_p & -\sin\theta_p & 0\\ 0 & \sin\theta_p & \cos\theta_p & 0\\ s_P & 0 & 0 & 1\end{bmatrix}, \ (p=B,\, C,\, D). \qquad (7)$$

The matrixes of the binary links have the following views:

- the binary link AB of RC type

$$\mathbf{G}_{AB}^{RC}(a_{AB},\alpha_{AB},c_{AB})=\begin{bmatrix}1 & 0 & 0 & 0\\ a_{AB} & 1 & 0 & 0\\ 0 & 0 & \cos\alpha_{AB} & \text{-}\sin\theta_{AB}\\ c_{AB} & 0 & \sin\theta_{AB} & \cos\alpha_{AB}\end{bmatrix}, \qquad (8)$$

- the binary links BC and CD of CC type

$$\mathbf{G}_{jk}^{CC}(a_{jk},\alpha_{jk})=\begin{bmatrix}1 & 0 & 0 & 0\\ a_{jk} & 1 & 0 & 0\\ 0 & 0 & \cos\alpha_{jk} & \text{-}\sin\alpha_{jk}\\ 0 & 0 & \sin\alpha_{jk} & \cos\alpha_{jk}\end{bmatrix}, \ (j=A,B;\ \ k=B,C). \qquad (9)$$

4 Conclusion

The structural scheme of the spatial parallel manipulator of RCCC type is synthesized. The structural scheme of this parallel manipulator is formed by connection of the link of the spatial anthropomorphic manipulator of RC type with a frame by the binary link of CC types. The matrixes of the binary link of RC and CC types and the revolute and cylindrical kinematic pairs are composed. The elements of the matrixes of the binary links of RC and CC types are constant, and they characterize the geometry of the binary links. The elements of the revolute and cylindrical kinematic pairs are variable, and they characterize the relative positions of their elements.

Литература

1. Zh.Zh. Baigunchekov, M.B. Izmambetov, and N.Zh. Baigunchekov. Kinematics of the Spatial Parallel Manipulator of RCCC Type. World Congress on Engineering WCE2013, London, UK, 3-5 July, 2013 (it is presented).

2. Zh.Zh. Baigunchekov, S.U. Joldasbekov. Modular Synthesis of Spatial Manipulating Devices of High Classes. Proceedings of the Twelfth International Conference on CAD/CAM Robotics and Factories of the Future. Middlesex University, London, England, 14-16 August, 1996, pp. 685-690.

3. Zh.Zh. Baigunchekov, Raj Gill, Antony S. White, N.Zh. Baigunchekov. The Basis of Structural and Parametric Synthesis of The Parallel Manipulators with Functionally Independent Drives (Part I and Part II). Proceedings of the International Conference on Gearing, Transmissions, and Mechanical Systems, Nottingham Trent University, UK, 3-6 July, 2000, pp.1-19.

4. I.I. Artobolevskiy. Theory of Mechanisms and Machines. Moscow, 2003, 538 p.

References

1. Zh.Zh. Baigunchekov, M.B. Izmambetov, and N.Zh. Baigunchekov. Kinematics of the Spatial Parallel Manipulator of RCCC Type. World Congress on Engineering WCE2013, London, UK, 3-5 July, 2013 (it is presented).

2. Zh.Zh. Baigunchekov, S.U. Joldasbekov. Modular Synthesis of Spatial Manipulating Devices of High Classes. Proceedings of the Twelfth International Conference on CAD/CAM Robotics and Factories of the Future. Middlesex University, London, England, 14-16 August, 1996, pp. 685-690.

3. Zh.Zh. Baigunchekov, Raj Gill, Antony S. White, N.Zh. Baigunchekov. The Basis of Structural and Parametric Synthesis of The Parallel Manipulators with Functionally Independent Drives (Part I and Part II). Proceedings of the International Conference on Gearing, Transmissions, and Mechanical Systems, Nottingham Trent University, UK, 3-6 July, 2000, pp.1-19.

4. I.I. Artobolevskiy. Theory of Mechanisms and Machines. Moscow, 2003, 538 p.

Резюме

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АЦЦЦ ТИПТІ КЕҢІСТІКТІК ПАРАЛЛЕЛЬДІ МАНИПУЛЯТОРДЫҢ

ҚҰРЫЛЫМДЫҚ СИНТЕЗІ МЕН ГЕОМЕТРИЯСЫ

Бұл мақалада АЦЦЦ (А – айналмалы кинематикалық жұп, Ц – цилиндрлік кинематикалық жұп) типті кеңістіктік параллельді манипулятор қарастырылады. Бұл кеңістіктік параллельді манипулятор үш еркіндік дәрежелі АЦ типті антропоморфты манипулятордың атқарушы буынын ЦЦ типті бинарлы буын арқылы тағанға жалғау негізінде құрастырылған. Қарастырылып отырған параллельді манипулятордың геометриясын сипаттау үшін кинематикалық жұптардың әрбір элементіне бекітілген оң декарттық координаталар жүйесі қолданылады. Параллельді манипулятор құрылымдық сұлбасының тұрақты және айнымалы параметрлері айқындалды. Тұрақты параметрлер буындар геометриясын сипаттаса, айнымалы параметрлер кинематикалық жұптар элементтерінің өзара орналасуларын сипаттайды.

Кілт сөздер: параллельді манипулятор, цилиндрлік және айналмалы кинематикалық жұптар, құрылымдық синтез.

Резюме

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СТРУКТУРНЫЙ СИНТЕЗ И ГЕОМЕТРИЯ ПРОСТРАНСТВЕННОГО

ПАРАЛЛЕЛЬНОГО МАНИПУЛЯТОРА ВЦЦЦ ТИПА

В данной статье рассматривается пространственный параллельный манипулятор ВЦЦЦ типа (В – вращательная кинематическая пара, Ц – цилиндрическая кинематическая пара). Данный параллельный манипулятор сформирован соединением рабочего звена антропоморфного манипулятора ВЦ типа с тремя степенями свободы со стойкой посредством бинарного звена ЦЦ типа. Для описания геометрии рассматриваемого параллельного манипулятора используются правые декартовы системы координат, жестко связанные с каждым элементом кинематических пар. Получены постоянные и переменные параметры структурной схемы параллельного манипулятора. Постоянные параметры характеризуют геометрию звеньев, а переменные параметры характеризуют относительные положения элементов кинематических пар.

Ключевые слова: параллельный манипулятор, цилиндрические и вращательные кинематические пары, структурный синтез.

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