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THE DESIGN OF UNIQUE MECHANISMS AND MACHINES. II

Abstract. A cardinal breakthrough is possible in the transition of mechanisms of lower class (class II) to high class (class IV and above) to design new mechanisms and machines. For the first time a new concept based on approximation theory is offered for mechanisms of high class aimed at solving kinematic, kinetostatic and dynamic problems. Methods, algorithms and programs are developed to define the position of links and reaction forces in the joints for mechanism of class IV at any given accuracy. A numerical experiment has shown a huge advantage of mechanism of class IV to design a new mechanism for aircraft's chassis (the mechanism of the robotics and auto crane's boom outreach having a heavy payload), as well as for control devices of working bodies with high speeds for hydraulic hammers and presses. At the same time minimum of reaction forces in the joints for these mechanisms as well as the minimum of balancing force to select the required drive with low power is provided.

Key words: kinetostatic, dynamics, mechanism of high class, mechanical engineering, robotics.

Introduction. The kinematic-dynamic model for mechanism of high class is described by differential-algebraic equations (DAE)[1]. Some questions of the investigation of DAE are given in [2-5]. The complete analysis of mechanisms of high class involves the simultaneous solution of kinematic, kinetostatic and dynamic problems. According to the classical theory of mechanisms and machines a separate solution of complex problems is considered. Planar lever mechanism of class IV as the basic mechanism out of all mechanisms of high class and in much the same way a four-link mechanism out of mechanisms of lower class II are going to be studied.

This work is devoted to the development of a new calculation theory for the underlying mechanism of class IV done on the basis of the theory of differential equations and the approximation theory. In this article we consider singular differential-algebraic equations and a power analysis of these mechanisms.

The proposed methods, algorithms and the held computational experiment made possibilities to identify the unique characteristics of the above mentioned mechanism of class IV and their use in various scientific and technological fields (in the mechanisms like departure chassis of an aircraft, load-lifting cranes, presses, robots and other devices).

The common model for mechanism of high class. Suppose the mechanism of high class (MHC) consists of n moving links. Numbers of output links vary from 1 to n-m, and the number of input ones varies from n-m +1 to n, m is the number of input links directly related to drive units (Figure 1). The proposed mechanism of the numbering units enables the use of vector-matrix notation in solving various equations in kinematics and dynamics.

Then the general model for mechanism of class IV (n=6, m=2) is represented in the form:

- differential equations of this mechanism's dynamics having two degrees of freedom (two generalized coordinates, n=6, m=2) are:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_j}\right) - \frac{\partial L}{\partial q_j} = Q_j \,, j = \overline{1,m} \qquad (1)$$

and having the initial conditions

$$q_j(t_0), \dot{q}_j(t_0) \tag{2}$$

where L is the Lagrangian, q_j, $\dot{q}_j$, Q_j are generalized coordinates, velocity and force.

The kinematic model of the mechanism of the IV class (shown in figure 1) is described by a system of trigonometric equations:

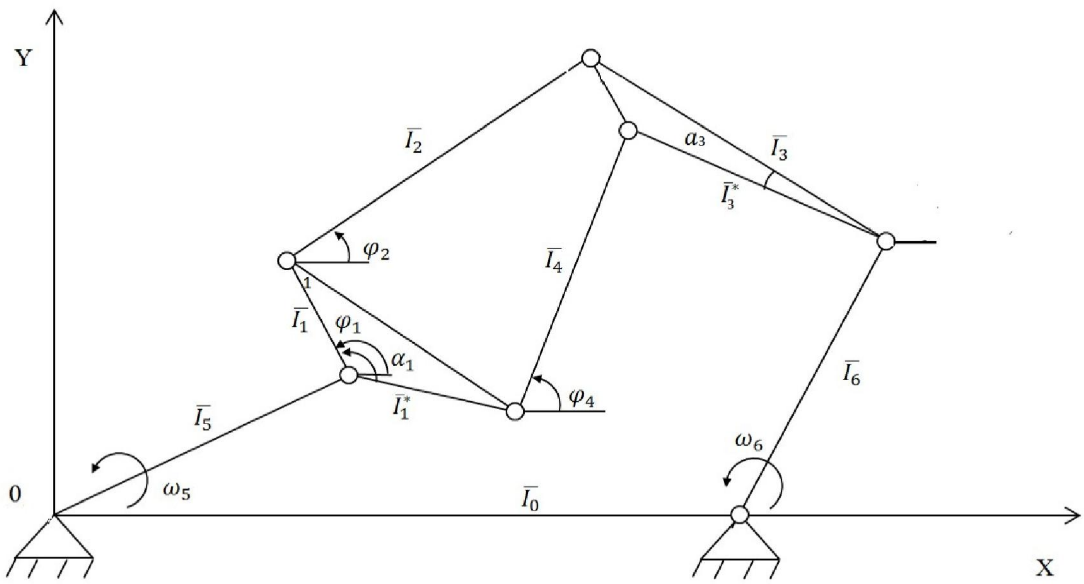

Figure 1 – Mechanism of class IV having rotational pairs

$$\begin{gathered}
l_1 \cos\varphi_1 + l_2 \cos\varphi_2 + l_3 \cos\varphi_3 + l_5 \cos\varphi_5 - l_6 \cos\varphi_6 - l_0 \cos\varphi_0 = 0, \\
l_1 \sin\varphi_1 + l_2 \sin\varphi_2 + l_3 \sin\varphi_3 + l_5 \sin\varphi_5 - l_6 \sin\varphi_6 - l_0 \sin\varphi_0 = 0, \\
l_1^* \cos(\varphi_1 - \alpha_1) - l_3^* \cos(\varphi_3 + \alpha_3) + l_4 \cos\varphi_4 + l_5 \cos\varphi_5 - l_6 \cos\varphi_6 - l_0 \cos\varphi_0 = 0, \\
l_1^* \sin(\varphi_1 - \alpha_1) - l_3^* \sin(\varphi_3 + \alpha_3) + l_4 \sin\varphi_4 + l_5 \sin\varphi_5 - l_6 \sin\varphi_6 - l_0 \sin\varphi_0 = 0.
\end{gathered} \tag{3}$$

Systems (1), (3) are a system of differential-algebraic equations (DAE). This terminology is accepted by scientists all over the world.

From the system (3) we have the dependence of the angular coordinates φ of the output links on the angular coordinates q of the input links of the mechanism:

$$\varphi(t) = \varphi(q(t)). \tag{4}$$

It should be noted that in the first part the system of trigonometric Equations (3) were presented in a differential form. Therefore, the differential form of the system (3) has its advantages and disadvantages associated with the matrix A. Only the case when the DAS is related to the ordinary differential equations (ODE) for $|A| \neq 0$ is considered. The singularity of the DAY arises when $|A| = 0$.

In this case, the application of numerical Runge-Kutta's methods is impossible. It is necessary to look for other approaches. Known approaches of foreign [2, 3] and russian [4] scientists are not very suitable for their use, since the error in the developed numerical methods is quite large. This error violates the reliability of the kinematic model (3).

Task 1. Solve the general model (1) - (3) for mechanism of class IV using approximation theory and Runge-Kutta's method for $|A| \neq 0$ or $|A| = 0$.

We first determine the Lagrangian L for the mechanism of class IV

$$L = \sum_{i=1}^{4}\frac{m_i l_i^2 \dot{\varphi}_i^2}{2} - \sum_{i=1}^{4} m_i g l_i sin\varphi_i + \sum_{j=5}^{6}\frac{m_j l_j^2 \dot{q}_j^2}{2} - \sum_{j=5}^{6} m_j g l_j sinq_j +$$
$$+\frac{m_1^* l_1^{*2} \dot{\varphi}_1^2}{2} + m_1^* g l_1^* sin(\varphi_1 - \alpha_1) + \frac{m_3^* l_3^{*2} \dot{\varphi}_3^2}{2} + m_1^* g l_1^* sin(\varphi_3 + \alpha_3), \quad (5)$$

where m is the mass of the links, g is the acceleration due to gravity. When the Lagrange's operator of the second kind is applied to the function (7), the following derivatives are necessary

$$\dot{\varphi}_i(t) = \left(\frac{\partial\varphi_i(q)}{\partial q}, \dot{q}(t)\right), \ddot{\varphi}_i(t) = \left(\frac{\partial\varphi_i(q)}{\partial q}, \ddot{q}(t)\right) + \dot{q}(t)'\frac{\partial^2\varphi_i(q)}{\partial q^2}\dot{q}(t), i = 1, \dots, n-m \quad (6)$$

Then the system (1) can be written in the form of a normal Cauchy form:

$$\dot{q} = f\left(q(t), \varphi(t), \frac{\partial\varphi}{\partial q}(t), \frac{\partial^2\varphi}{\partial q^2}(t), M(t)\right), t \in [t_0, t_1] \quad (7)$$

where f is a vector- function of dimension $2mx1$.

Approximation theory studies the question of the possibility of approximate representation of some mathematical objects by other objects of simpler nature. Now us show the possibility of applying the theory of approximations to the numerical solution of the Cauchy problem (1)-(3). Let $\Delta\varphi$ be the error in calculating the angular coordinates, then we can use the approximation theory.

Lemma. For the numerical realization of the trigonometric identity

$$cos^2\varphi + sin^2\varphi = 1 \quad (8)$$

is applied formula

$$\cos(\varphi + \Delta\varphi)cos\varphi + sin(\varphi + \Delta\varphi)sin\varphi = cos\Delta\varphi. \quad (9)$$

Proof. We apply trigonometric transformations. Then the equality (8) takes the form: $\cos(\varphi + \Delta\varphi)cos\varphi + sin(\varphi + \Delta\varphi)sin\varphi = (cos\varphi cos\Delta\varphi - sin\varphi sin\Delta\varphi)cos\varphi + (sin\varphi cos\Delta\varphi + cos\varphi sin\Delta\varphi)sin\varphi$. We pirve such terms in this ratio. Then we get $\cos(\varphi + \Delta\varphi)cos\varphi + +sin(\varphi + \Delta\varphi)sin\varphi = cos\Delta\varphi$ .It follows from the last expression that $\lim_{\Delta\varphi\to 0} cos\Delta\varphi = 1$. This limit ensures the fulfillment of the trigonometric identity.

Note 1. We introduce the notation $\delta = cos\Delta\varphi$. Then, by choosing δ (or $\Delta\varphi$), the relation $1-\delta = \varepsilon$ establishes the fulfillment of the trigonometric identity with a given accuracy.

Theorem 1. The numerical realization of the system of trigonometric equations (3) can be represented as a system of linear algebraic equations.

Proof. On the basis of the lemma, the trigonometric system (3) after applying the scalar product and excluding the angular coordinates φ_2, φ_4 goes into the system of linear equations for variables $\cos\varphi_1^{k+1}$, $\sin\varphi_1^{k+1}$, $\cos\varphi_3^{k+1}$, $\sin\varphi_3^{k+1}$:

$$\delta l_2^2 = (-l_1 \cos\varphi_1^{k+1} - l_3\cos\varphi_3^{k+1} - l_5\cos\varphi_5^{k+1} + l_6\cos\varphi_6^{k+1} + l_0\cos\varphi_0)*$$
$$*(-l_1 \cos\varphi_1^{k} - l_3\cos\varphi_3^{k} - l_5\cos\varphi_5^{k} + l_6\cos\varphi_6^{k} + l_0\cos\varphi_0)+$$
$$+(-l_1 \sin\varphi_1^{k+1} - l_3\sin\varphi_3^{k+1} - l_5\sin\varphi_5^{k+1} + l_6\sin\varphi_6^{k+1} + l_0\sin\varphi_0)*$$
$$*(-l_1 \sin\varphi_1^{k} - l_3\sin\varphi_3^{k} - l_5\sin\varphi_5^{k} + l_6\sin\varphi_6^{k} + l_0\cos\varphi_0), \quad (10)$$

$$\delta l_4^2 = (-l_1 \cos(\varphi_1^{k+1} - \alpha_1) - l_3\cos(\varphi_3^{k+1} + \alpha_3) - l_5\cos\varphi_5^{k+1} + l_6\cos\varphi_6^{k+1} + l_0\cos\varphi_0)*$$
$$*(-l_1 \cos(\varphi_1^{k} - \alpha_1) - l_3\cos(\varphi_3^{k} + \alpha_3) - l_5\cos\varphi_5^{k} + l_6\cos\varphi_6^{k} + l_0\cos\varphi_0)+$$
$$+(-l_1 \sin(\varphi_1^{k+1} - \alpha_1) - l_3\sin(\varphi_3^{k+1} + \alpha_3) - l_5\sin\varphi_5^{k+1} + l_6\sin\varphi_6^{k+1} + l_0\sin\varphi_0)*$$
$$*(-l_1 \sin(\varphi_1^{k} - \alpha_1) - l_3\sin(\varphi_3^{k} + \alpha_3) - l_5\sin\varphi_5^{k} + l_6\sin\varphi_6^{k} + l_0\cos\varphi_0),$$
$$\cos\varphi_1^{k+1}\cos\varphi_1^{k} + \sin\varphi_1^{k+1}\sin\varphi_1^{k} = \delta, \quad (11)$$

$$\cos\varphi_3^{k+1}\cos\varphi_3^k + \sin\varphi_3^{k+1}\sin\varphi_3^k = \delta$$

where κ is iteration number, κ=0, 1, 2, …, n.

We determine the variables $\cos\varphi_1^{k+1}$, $\sin\varphi_1^{k+1}$, $\cos\varphi_3^{k+1}$, $\sin\varphi_3^{k+1}$ from the systems (10), (11) and substitute them into the system (3).

Then we find the quantities $\cos\varphi_2^{k+1}$, $\sin\varphi_2^{k+1}$, $\cos\varphi_4^{k+1}$, $\sin\varphi_4^{k+1}$:

$$\begin{aligned}
\cos\varphi_2^{k+1} &= (-l_1\cos\varphi_1^{k+1} - l_3\cos\varphi_3^{k+1} - l_5\cos\varphi_5^{k+1} + l_6\cos\varphi_6^{k+1} + l_0\cos\varphi_0)/l_2,\\
\sin\varphi_2^{k+1} &= (l_1\sin\varphi_1 + l_3\sin\varphi_3^{k+1} + l_5\sin\varphi_5^{k+1} - l_6\sin\varphi_6 - l_0\sin\varphi_0)/l_2,\\
\cos\varphi_4^{k+1} &= (-l_1^*\cos(\varphi_1-\alpha_1) - l_3^*\cos(\varphi_3^{k+1}+\alpha_3) - l_5\cos\varphi_5^{k+1} + l_6\cos\varphi_6^{k+1} + l_0\cos\varphi_0)/l_4,\\
\sin\varphi_4^{k+1} &= (-l_1^*\sin(\varphi_1-\alpha_1) - l_3^*\sin(\varphi_3^{k+1}+\alpha_3) - l_5\sin\varphi_5^{k+1} + l_6\sin\varphi_6^{k+1} + l_0\sin\varphi_0)/l_4.
\end{aligned} \tag{12}$$

We note that for $k = 0$ in the linear systems (10-12), the initial values of the functions $cos\varphi_i(t_k)$, $sin\varphi_i(t_k)$ are determined on the base [5] .

Note 2. The left-hand sides of the system (10) are the scalar product of the vectors (l_2^k, l_2^{k+1}), (l_4^k, l_4^{k+1}) on the k and $k+1$ steps. Let $\delta = 1$. In this case, the equation (11) asserts that the projection of the vector l_2^k on to the direction l_2^{k+1} is equal to l_2 . Obviously, the length of the vector l_2^{k+1}, found from the system (10), will not be equal to l_2 . Therefore, the normalization of the vector l_2^{k+1} is required. This is true for the vectors l_4^k, l_4^{k+1} and the unit vectors in the last two equations (11) of the whole system, also for the right-hand side of the system (10), which is the scalar product of unit vectors and vectors l.

We introduce the notation $x_i^k = cos\varphi_i(t_k)$, $y_i^k = sin\varphi_i(t_k)$. These values are then normalized: $x_i^k = \frac{x_i^k}{((x_i^k)^2 + (y_i^k)^2)^{\frac{1}{2}}}, y_i^k = \frac{y_i^k}{((x_i^k)^2 + (y_i^k)^2)^{\frac{1}{2}}}, i = 1,2,3,4.$

Further, we find the angular coordinates:

$$\varphi_i^k = \varphi_i(t_k) = arctg\frac{y_i^k}{x_i^k} + n\pi, \tag{13}$$

where $x_i^k = cos\varphi_i(t_k)$, $y_i^k = sin\varphi_i(t_k)$.

The initial values of variables $\varphi_i(t_k)$, $\varphi_i(t_k)$ are determined on the base formula (14). The discrete velocities $\dot{\varphi}^k$ and the accelerations $\ddot{\varphi}^k$ in the Lagrange's operator are found from the formulas of numerical differentiation [6] by the found angular coordinates $\varphi(t_k)$.

In conclusion, we represent the continuous system (7) in a discrete form:

$q^{k+1} = q^k + f\left(q(t_k), \varphi(t_k), \frac{\partial\varphi}{\partial q}(t_k), \frac{\partial^2\varphi}{\partial q^2}(t_k), M(t_k)\right)h$, k=0, 1, 2, …, n (14) where $q^k = q(t_k), \varphi^k = \varphi(t_k)$, $(\frac{\partial\varphi}{\partial q})^k = \frac{\partial\varphi}{\partial q}(t_k), \left(\frac{\partial^2\varphi}{\partial q^2}\right)^k = \frac{\partial^2\varphi}{\partial q^2}(t_k), M^k = M(t_k), t_k = t_0 + kh, h = \Delta t.$ Here, $f\left(q(t_k), \varphi(t_k), \frac{\partial\varphi}{\partial q}(t_k), \frac{\partial^2\varphi}{\partial q^2}(t_k), M(t_k)\right)$ is a vector function, h is step of integration. Further, we define the required partial derivatives

$$\frac{\partial\varphi_i}{\partial q_j}(t_k) = \frac{\dot{\varphi}_i(t_k)}{\dot{q}_j(t_k)}, \frac{\partial^2\varphi_i}{\partial q_j^2}(t_k) = \frac{\ddot{\varphi}_i(t_k)}{\ddot{q}_j(t_k)}, i = 1, \ldots, n-m, j = n-m+1, \ldots, n .$$

We formulate this result in the form

Theorem 2. The solution of a system of differential-algebraic equations is found from the system of linear equations (10-12), (14).

Note 3. The accuracy of the solution of the system (1-3) (DAE) can be improved by representing the vector function $f\left(q(t_k), \varphi(t_k), \frac{\partial\varphi}{\partial q}(t_k), \frac{\partial^2\varphi}{\partial q^2}(t_k), M(t_k)\right)$ in system (14) on the basis of Runge-Kutta numerical methods[65].

The kinetostatic method for the mechanism of class IV. The proposed method of kinematic calculating and method of kinetostatics based on D'Alembert's principle is put as the basis for the mechanism force calculation. The results of the study of the force parameters serve as the basis for the calculation of the strength and stiffness of the mechanism of class IV. Without loss of generality we assume $l_6=0$. Kinematic scheme of power analysis for the mechanism of class IV is shown in Figure 2.

Task 2. Define the reaction forces in the joints *A*, *B*, *C*, *D* and *E* of the mechanism of class IV under the influence of external moment *M*.

Using the method of calculation of the kinematic parameters [5], the coordinates of these joints are defined by:

$$x_A = l_5\cos\varphi_5,\ y_A = l_5\sin\varphi_5,\ x_B = l_5\cos\varphi_5 + l_1\cos\varphi_1,\quad y_B = l_5\sin\varphi_5 + l_1\sin\varphi_1,$$

$$x_C = l_5\cos\varphi_5 + l_1^*\cos(\varphi_1-\alpha_1),\ y_C = l_5\sin\varphi_5 + l_1^*\sin(\varphi_1-\alpha_1),$$

$$x_D = l_5\cos\varphi_5 + l_1\cos\varphi_1 + l_2\cos\varphi_2,\ y_D = l_5\sin\varphi_5 + l_1\sin\varphi_1 + l_2\sin\varphi_2,$$

$$x_E = l_5\cos\varphi_5 + l_1^*\cos(\varphi_1-\alpha_1) + l_4\cos\varphi_4,\ y_E = l_5\sin\varphi_5 + l_1^*\sin(\varphi_1-\alpha_1) + l_4\sin\varphi_4.$$

We define the coordinates of the point of intersection *H* of the lines in figure 2, passing through the points *D*, *B* and *H*, *E*, *C* and *H*, *A* and *H*

$$A_i x + B_i y + C_i = 0,\quad i = 1,2,3$$

where

$$A_1 = -(y_D - y_B),\quad B_1 = x_D - x_B,\quad C_1 = (y_D - y_B)x_B - y_B(x_D - x_B),\ A_2 = -(y_E - y_C),$$

$$B_2 = x_E - x_C,\quad C_2 = (y_E - y_C)x_E - y_E(x_E - x_C),\ A_3 = -(y_A - y_H),\quad B_3 = x_A - x_H,$$

$$C_3 = (y_A - y_H)x_A - y_A(x_A - x_H),\ x_H = \frac{B_1C_2 - B_2C_1}{A_1B_2 - A_2B_1},\quad y_H = \frac{C_1A_2 - C_2A_1}{A_1B_2 - A_2B_1}.$$

We form the equation of balance of the base link 1 by equating the sum of the forces acting on this link:

$$\overline{F_1} + \overline{F_2} + \overline{F_3} = 0$$

The vector equation of equilibrium of the force is decomposed into two components in the projections on the axis of the fixed system of coordinates:

$$F_1\cos\varphi_2 + F_2\cos\varphi_4 + F_3\cos\beta = 0,$$

$$F_1\sin\varphi_2 + F_2\sin\varphi_4 + F_3\sin\beta = 0,$$

where

$$\beta = arctg(-\frac{A_3}{B_3}).$$

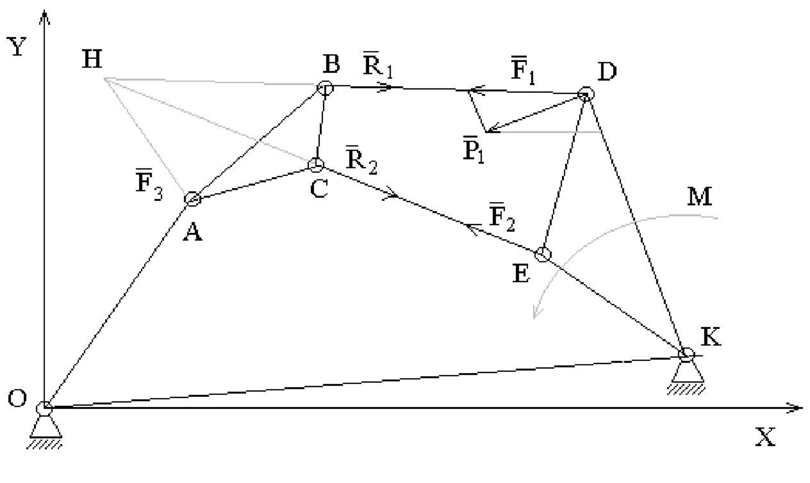

Figure 2 – Kinetostatic analysis for the mechanism of class IV

The reaction forces $\overline{F_1}, \overline{F_2}$ and $\overline{F_3}$ in the joints A, B, and C of the base link 1 are arisen due to the action of constant moment M on output link 3 with fixed (input) link 5. Acting on output link 3 the moment is $M = P_1 l_3 + P_2 l_3^*$. Here, l_3 and l_3^* are the length of the vectors of base link 3. According to the plan of force we determine (see Fig.2.):

$$P_1 = F_1 \cos(90^\circ + \varphi_2 - \varphi_3),$$

$$P_2 = F_2 \cos(90^\circ + \varphi_3 + \alpha_3 - \varphi_4).$$

Substituting the last formula in scalar equations (17), we obtain a system of equations to determine the reaction forces $\overline{F}_1$, $\overline{F}_2$ and $\overline{F}_3$:

$$\begin{cases} F_1 \cos\varphi_2 + F_2 \cos\varphi_4 + F_3 \cos\beta = 0 \\ F_1 \sin\varphi_2 + F_2 \sin\varphi_4 + F_3 \sin\beta = 0 \\ l_3 F_1 \cos(90^\circ + \varphi_2 - \varphi_3) + l_3^* F_2 \cos(90^\circ + \varphi_3 + \alpha_3 - \varphi_4) = M \end{cases}$$

In conclusion, it should be noted that a method, an algorithm and a program for determining reaction forces in the kinematic pairs of the mechanism of class IV have been developed based on the proposed method of power analysis.

Discussion of results. Power analysis makes it possible to calculate the strength of the mechanism of class IV parameters and to select the power for the desired drive unit. Thus, a fresh approach to make a simultaneous solution of kinematic, kinetostatic and dynamic problems of the mechanism of class IV is offered. The obtained results are easy to apply to mechanisms of high class with a larger number of closed contours. The importance of the fundamental scientific result presenting in brief the theory of mechanisms of high class lies in its practical application. The question always arises: how to use the theory actually proposed in a compressed form, and the unique properties of these mechanisms in the design of new devices and machines.

For the first time the programs on the Delphi's language calculate position and reaction force in the mechanism of class IV with any desired accuracy. The results of program on the position of links and reaction forces in the joints for the mechanism of class IV. Initial data: L_0 =10cm, L_1 =2cm, L_1^* =2cm, L_2 =8,268cm, L_3 =5cm, L_3^* =5cm, L_4 =5,9133cm, L_5 =4cm,L_6 =0, α_1 =60^0, α_3 =30^0, φ_0 =0, $\varepsilon = 0{,}001$, φ_{5min} =70^0, φ_{5max} =105^0, φ_{3min} =70^0, φ_{3max} =100^0, h =0,05^0, $\dot{\varphi}_5$=0,01rad/s. The program defines values of the angular coordinates of all remaining links at the possible ranges of variation φ_{3min} =70$^0 \le \varphi_3 \le \varphi_{3max}$ =100^0, $\varphi_{5min} = 70^0 \le \varphi_5 \le \varphi_{5max}$ =105^0. Separately we give the initial values of the angular coordinate of input link 5 φ_5 =90,0499999999989^0 and of output link3 φ_3=90,0499999999989^0 in accordance with which the movement of the mechanism starts. If we change the angular coordinate φ_5 of input link 5 90,0499999999989^0 to 90,2499999999988^0

The positions and forces are listed in tables 1and 2.

Table 1 – Angular coordinate of links for mechanism of class IV

φ_1	φ_2	φ_3	φ_4	φ_5
30.151212399452	-0.031675872130	90.0499999999989	12.928351949062	90.0499999999989
30.153170114784	-0.032123943447	90.0999999999989	12.907880756584	90.0999999999989
30.155201340299	-0.032593556243	90.1499999999989	12.887379206970	90.1499999999989
30.155693019626	-0.032636365534	90.1499999999989	12.879818673972	90.1999999999989
30.157800302286	-0.033107168760	90.1999999999989	12.859325664381	90.2499999999988

Table 2 – Reaction forces in the joints for mechanism of class IV

fr[1]	fr[2]	fr[3]
0,085501549459072	-0,0179259921115466	0,0241681781581009
0,0853804108253469	-0,0179268654072137	0,024138568162871
0,0852599951693558	-0,0179278751364108	0,0241091893026834
0,0852777526589473	-0,0179964249228941	0,0241643846455302
0,0852777526589473	-0,0179974850000152	0,0241350541017292

These mechanisms can be used in the design of robots and cranes with high lifting capacity, mechanisms of departure chassis of a fighter aircraft landing at high speed on aircraft carriers, heavy transport and passenger aircrafts landing on the airfield, presses and hydraulic hammers at a significant rate of working body movements, and etc.

During landing of heavy airplanes on an airfield and of a fighter aircraft on an aircraft carrier at the moment of wheel contact with bearing surface there is an instantaneous force (instant impact) on the mechanism of chassis, and a difficult task is to keep the load by drive with minimum power. To prevent damage it is necessary to provide a minimum of reaction forces in the joints of the mechanism of chassis. This is possible if the chassis design on the basis of the mechanism of class IV.

From numerical results it is evident that a wheel can be attached to the joints E or D, as well as joints O and K to housing of an aircraft (Figure 2). Reaction forces in the joints D, E and of output link 3 are equal to fr[1] = 0,177489607188975 fr[2] = 0.0235637144272305 respectively, and balancing force is generated by the drive fr[3] = - 0.200247062147046 for input link 5. It should be noted that reaction forces in joints are reduced 5 or more times as compared with the influence of instantaneous maximum power $M = 1$ at a wheel contact point.

The latter fact allows increasing the bearing capacity and the service life of a new mechanism of chassis and the range of speed change at landing. Thus, we provide a higher degree of safety of an aircraft.

Conclusion. For the first time we make the following conclusions:

- a new direction is suggested in simultaneous calculation of kinematics, kinetostatics and dynamics of mechanisms of high class on the basis of the theory of differential equations and approximation theory;
- methods and algorithms for determining the position of links and reaction forces in the joints of the mechanism of IV class are developed;
- a program for calculation of kinetostatic and dynamic parameters in the mechanism of class IV with any given accuracy is written;
- the use of mechanism of class IV in the design of a new chassis in aircrafts and mechanisms of departure chassis of a fighter aircraft landing on aircraft carriers at high speed, heavy transport and passenger aircrafts landing on the airfield and the mechanism of the auto crane's boom outreach having a heavy payload as well as for movable operating elements of the hammer's actuating units and for high speed presses is mathematically justified.

This ensures minimum of reaction forces in the joints of these mechanisms and minimum of balancing power to select the required drive with low power.

REFERENCES

[1] Sinchev B., Mukhanova A.M. The design of unique mechanisms and machines. I // News of the National Academy of Sciences of Republic of Kazakhstan. Series of Geology and Technical Sciences. 2018. Vol. 1, N 427. P. 111-117 (in Eng.).

[2] Gear C.W. The simultaneous numerical solution of differential-algebraic equations. IEEE Trans. Circuit Theory. 1971. CT.-18. P. 89-95 (in Eng.).

[3] Petzold L.R. A description of DASSL: A differential-algebraic system solver. Scient Comput Amsterdam: North-Holland, 1983. 65 p. (in Eng.).

[4] Shalashilin V.I., Kuznetsov E.B. The best continuation parameter // Reports RAS. 1994. Vol. 334, N 5. P. 566-568 (in Eng.).

[5] Sinchev B. Kinematic analysis of lever mechanisms // Reports of the National Academy of Sciences of Kazakhstan. 2003. N 3. P. 39-44 (in Russ.).

[6] Bakhvalov N., Zhidkov N., Kobelkov G. Numerical methods. M.: Science, 2002. 632 p. (in Russ.).

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БІРЕГЕЙ МЕХАНИЗМДЕРДІ ЖӘНЕ МАШИНАЛАРДЫ ЖОБАЛАУ. II

Аннотация. Жаңа механизмдер мен машиналарды жасау үшін төменгі сынып механизмдерінен (II класс) жоғары класты механизмдерге (IV және одан жоғары класс) көшу арқылы түбегейлі серпіліс жасауға болады. Кинематикалық, киностатикалық және динамикалық мәселелерді шешуге бағытталған жоғары дәрежелі механизмдер үшін жуықтау теориясы негізінде тұңғыш рет жаңа тұжырымдама ұсынылады. Сыныптың IV тетігі үшін топсаларда байланыстар мен реакциялық күштердің орналасуын анықтаудың әдістері, алгоритмдері және бағдарламалары әзірленді. Сандық эксперимент, үлкен өткізу қабілеті, сондай-ақ жоғары жылдамдықты гидравликалық балғамен және баспасөз бақылау құрылғылардың жұмыс органдарының үшін робот қолын және бум лифт кран механизмдерін ұшақтың жаңа шассиін дамыту үшін класс IV механизмі үлкен артықшылығы көрсетті. Сонымен қатар, осы механизмдердің ілмектеріндегі реакциялық күштердің минималды мәні, сондай-ақ қуатты төмен қуаттандыруды таңдау үшін ең аз теңдестіру күші қарастырылған.

Түйін сөздер: кинетостатика, динамика, жоғары дәрежелі механизм, машина жасау, робототехника.

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ПРОЕКТИРОВАНИЕ УНИКАЛЬНЫХ МЕХАНИЗМОВ И МАШИН. II

Аннотация. Кардинальный прорыв возможен при переходе от механизмов низшего класса (класс II) к механизмам высокого класса (класс IV и выше) для разработки новых механизмов и машин. Впервые предложена новая концепция, основанная на теории приближений для механизмов высокого класса, направленных на решение кинематических, кинетостатических и динамических задач. Разработаны методы, алгоритмы и программы для определения положений звеньев и сил реакций в шарнирах для механизма класса IV с любой точностью. Численный эксперимент продемонстрировал огромное преимущество механизма IV класса для разработки нового механизма шасси самолета, механизма руки роботов и подъема стрелы автокрана с большой грузоподъемностью, а также для устройств управления рабочими органами с высокими скоростями для гидравлических молотков и прессов. В то же время обеспечивается минимальное значение сил реакции в шарнирах этих механизмов, а также минимальная уравновешивающая сила для выбора требуемого привода с малой мощностью.

Ключевые слова: кинетостатика, динамика, механизм высокого класса, машиностроение, робототехника.

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