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NATURAL VIBRATION FREQUENCIES OF A THREE-LINK PIVOT-ROD MANIPULATOR

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A planar kinematic scheme of the manipulator with three degrees of freedom of the links is proposed. Manipulator links are statically determinate trusses. The connection of individual links is carried out using elements with variable lengths, such as hydraulic cylinders. It is assumed that the mass of the structure is concentrated in the nodes. Each massive node has two degrees of freedom. The first natural frequencies of the system oscillations are calculated depending on the position of the manipulator links.

Key words: truss, manipulator, oscillations, lower frequency.

Introduction

To facilitate the construction of the manipulator, its links can be made in the form of trusses [1-6]. The rigidity of the trusses, their mass and size affect the natural frequencies of the structure. In cases where the manipulator is designed for high-precision work, the accuracy of the positioning of the working element is an important qualitative characteristic of the device. Natural vibrations of the structure links introduce errors in the position of the tong and can disrupt the operation of the device. The greatest influence in this phenomenon is caused by vibrations with lower frequencies. If for static structures, the vibration frequencies are determined only by its rigidity, then in mechanisms, the vibration frequencies depend on the position of the links of the structure when it moves. In this paper, this dependence is considered for a planar model of a manipulator with three degrees of freedom.

Solution

The links of the device under consideration are the same and represent flat trusses with two panels, the length of each is *a*, and the height is *h* (Fig. 1).

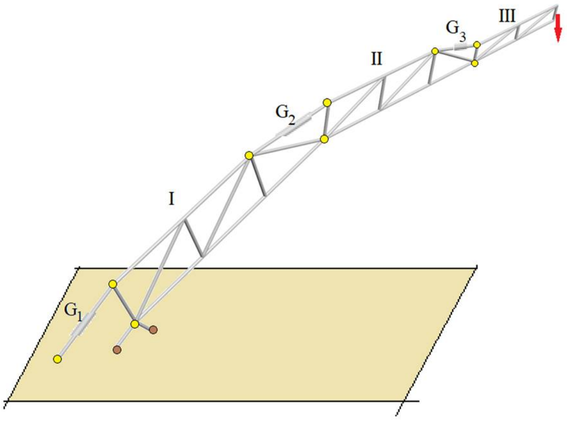

Fig. 1. The scheme of the manipulator

The total number of rods in the structure of k links is $\eta = k(m_0 + 3)$, where $m_0 = 4n + 1$ is the number of rods in one link of n panels, three rods in each link act as connections between them. One of the connection rods changes its length, driving the mechanism. This element can be made, for example, in the form of a hydraulic cylinder. In the figure, at k = 3, these elements are designated G_1, G_2, G_3. The position of the mechanism links is controlled by three independent tilt angles φ_1, φ_2, φ_3 (Fig. 2).

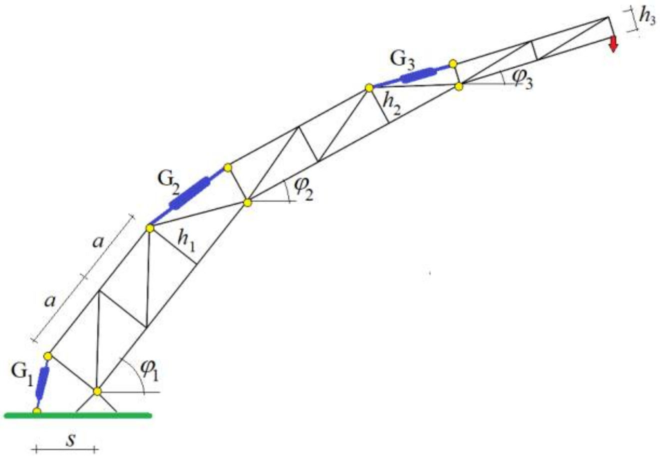

Fig. 2. Planar model of the mechanism

Consider the case of links with two panels in each, n = 2. The masses are located at all nodes, except for the node that is pivotally attached to the base. Given that each mass m in the node has two degrees of freedom on the plane, and we get in the considered construction with three links $2N$=34 degrees of freedom.

The equations of mass oscillations have the form:

$$\mathbf{J}_{2N}\ddot{\mathbf{Y}} + \mathbf{D}_{2N}\mathbf{Y} = 0, \tag{1}$$

where $\mathbf{D}_{2N}$ is the stiffness matrix, $Y = [x_1, x_2, \ldots x_N, y_1, y_2, \ldots y_N]^T$ is the vector of vertical and horizontal displacements of loads. All the masses μ are equal, $\mathbf{J}_{2N} = \mu\mathbf{I}_{2N}$ – is the diagonal inertia matrix, $\mathbf{I}_{2N}$ – the unit matrix, $\ddot{\mathbf{Y}}$ – the acceleration vector of nodes with masses. The inverse of the stiffness matrix $\mathbf{D}_{2N}$ is the matrix $\mathbf{B}_{2N}$, whose elements are calculated using Maxwell – Mohr's formula:

$$b_{i,j} = \sum_{\alpha=1}^{\eta-3} S_\alpha^{(i)} S_\alpha^{(j)} l_\alpha / (EF). \qquad (2)$$

Here, $S_\alpha^{(i)}$ is the force in the rod α from the action of a single vertical force at the node i, l_α is the length of the rod k, E is the elastic modulus of the rod material, F is the cross-sectional area of the rods. The stiffness of the rods is assumed to be the same. The three support rods are not deformed. The forces in these rods are not included in the sum (2). The forces in the rods included in the formula (2) are calculated in the *Maple* computer mathematics system. To do this, create arrays of node coordinates and lists of node numbers at the ends of the rods. Since the system contains the same elements (links-trusses), it is more convenient to perform this using procedure that creates lists of coordinates for each link, taking into account the rotation angle of the link and lists of vertex numbers.

Analysis of the obtained results

Consider a manipulator that has the following parameters: $E = 2 \cdot 10^5\,\mathrm{MPa}$ – the elastic modulus of the rods, $F = 1 \cdot 10^{-4}\,m^2$ the cross-sectional area of the elements, the mass at each node $\mu = 4kg$, the dimensions $a = 4\mathrm{m}$, $h_1 = 3\mathrm{m}$, $h_2 = 2\mathrm{m}$, $h_3 = 1\mathrm{m}$. The matrix eigenvalues are calculated using the *Eigenvalues* operator from the specialized linear algebra package *LinearAlgebra*. The calculation results are shown in Figure 3. The angle of inclination of the first link changes according to the law $\varphi_1 = 0.2 + 0.7j/K$, $K = 48$. The horizontal position of link III supports the hydraulic cylinder 3. The angle of inclination of link 2 is chosen so that the grip of the manipulator moves in a vertical straight line, performing a certain task: $\varphi_2 = \arccos(L - 2a\cos\varphi_1)/(2a)$, $L = 3a$. Figure 4 shows the corresponding positions of the manipulator in a schematic form.

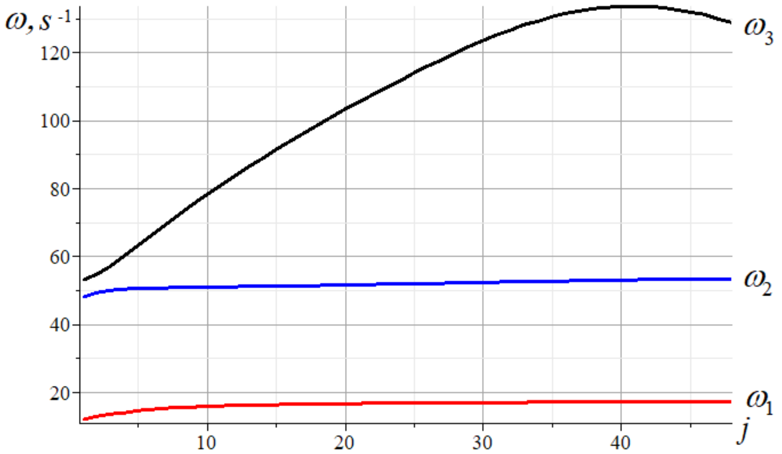

Fig. 3. Dependence of the first three frequencies on the position of the link I

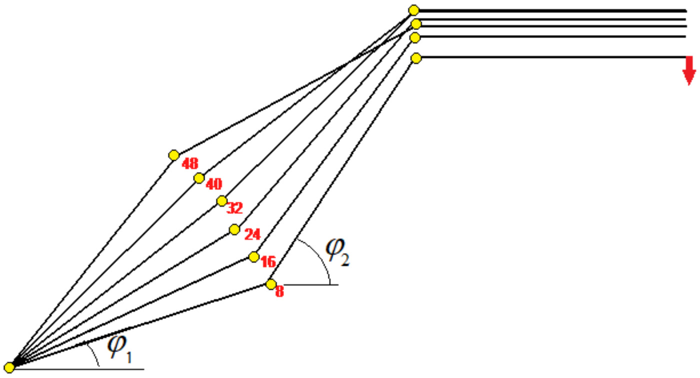

Fig. 4. Diagram of the six positions of the manipulator

It is characteristic that the first and second frequencies during the movement of the manipulator according to a given program almost do not change, while the third frequency first increases, then decreases. The considered algorithm for calculating frequencies allows you to get results for various programs embedded in the device. It should be noted that with a given program of movement of the grip, the solution for the angles φ_1, φ_2, φ_3 will be ambiguous. The optimal solution depends on the choice of the optimality evaluation criterion. Two criteria are most practical: minimizing the energy spent on the movement of the structure and limiting the forces in the elements (rods of variable length) G_1, G_2, G_3.

Conclusion

A planar model of the joint-rod structure of the manipulator, the movement of which is carried out by changing the lengths of the articulating rods, is proposed. An example of calculating the natural vibration frequencies of the mechanism is given. Even though the design has regular parts in its elements, it is not possible to perform an analytical calculation of frequencies using the induction method [5-7]. The calculation of the natural frequencies in the considered formulation can be supplemented by a power calculation and the solution of the problem of finding the most optimal kinematics of the device.

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ЧАСТОТЫ СОБСТВЕННЫХ КОЛЕБАНИЙ ТРЕХЗВЕННОГО ШАРНИРНО-СТЕРЖНЕВОГО МАНИПУЛЯТОРА

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Предлагается плоская кинематическая схема манипулятора с тремя степенями свободы. Звенья манипулятора представляют собой статически определимые фермы. Соединение отдельных звеньев осуществляется с помощью элементов с изменяемой длиной, например гидроцилиндров. Принимается, что масса конструкции сосредоточена в узлах. Каждый массивный узел имеет две степени свободы. Вычисляются первые собственные частоты колебаний системы в зависимости от положения звеньев манипулятора.

Ключевые слова: ферма, манипулятор, колебания, нижняя частота колебаний