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ASPECTS ON THE FUNCTIONAL OPTIMIZATION OF THE *TRR* –TYPE INDUSTRIAL ROBOT

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Abstract: *In the present paper, the authors aim to functionally optimize an industrial robot structure of a modular serial construction necessary for the creation of a flexible manufacturing cell with military application. The suggested algorithm highlights the obtaining of different equations of the robot's movement by using Lagrange's formalism. The calculus method provides the stressing of the concerned robot's total kinetic energy, determines both the virtual elementary mechanical work and the generated propulsive force and moments. Once the different movement equations have been obtained, the authors will determine the research servomotors necessary for taking into service the mobile equipment of the MO-1 prehension device attached to the robot structure. The scientific procedure aims at choosing those research servomotors which thus obtained through a mathematical algorithm meet feasibility, economy, profitableness and flexibility criteria, in order to serve with minimal energetic consumptions the flexible manufacturing cell.*

Keywords: *robot, dynamic, modelling, cell, optimization*

1. INTRODUCTION

At the design stage of industrial robots, an assessment of some indices is necessary, such as: the number of liberty degrees, the workspace shape and size, the mobility, the load capacity, the service factor, etc. Such an evaluation is possible only by conducting a dynamic study of the robots. The dynamic studies performed on industrial robots allow the choosing of the action motors, as well as the optimum arrangement of modules in a modular robot structure, so that the energy consumptions are minimal. For the dynamic modelling, the study of two fundamental mutual issues of the industrial robots' dynamics is aimed at. In the case of the first problem, also known as the direct problem, the following are determined: the time-depending variation laws of the coordinates and generalized speeds, being aware of the constructive mechanical parameters of the robot, the time-depending variation laws of motor forces and moments and the initial conditions of the robot movement. In the case of the second essential problem, also named the reverse problem, the following are determined: the time-depending variation laws of the motor agent (motor forces and moments) if the constructive mechanical parameters of the robot and the time-depending variation laws of the generalized coordinates are known. Among the industrial robots' dynamic study, we mention: Lagrange's formalism, the principle of dynamic virtual movements, the Newton-Euler method and the iterative method.

2. DYNAMIC MODELLING OF THE TRR-TYPE SERIAL-MODULAR ROBOT

For the dynamic modelling, Lagrange's formalism will be used; we also mention the fact that each module within the industrial robot's component has only one liberty degree, the movement being achieved through an independent action, command and positioning on each movement axis. For the dynamic modelling, according to the robot's kinematic schema presented in figure 1, the following measures will be considered: l_1, l_2, l_3 - constructive parameters of the robot, $q_k, \dot{q}_k, \ddot{q}_k, (k = 1 \div 3)$ - generalized coordinates, speeds and accelerations, $k = 1 \div 3$ - number of liberty degrees, $\overline{F}_1, \overline{M}_2, \overline{M}_3$ - motor force and moments, $\overline{P}_i, (i = 1 \div 3)$ - weight forces of the robot's modules, $J^{(2)}_{\Delta_2}, J^{(3)}_{\Delta_3}$ - the mechanical inertia moment related to the (Δ_2) axis of the rotation module 2 mobile equipment and of the module 3 part interdependent with module 2, i.e. the mechanical inertia moment related to the (Δ_3) axis of the rotation module 3 mobile equipment and of the prehension device part interdependent with module 3.

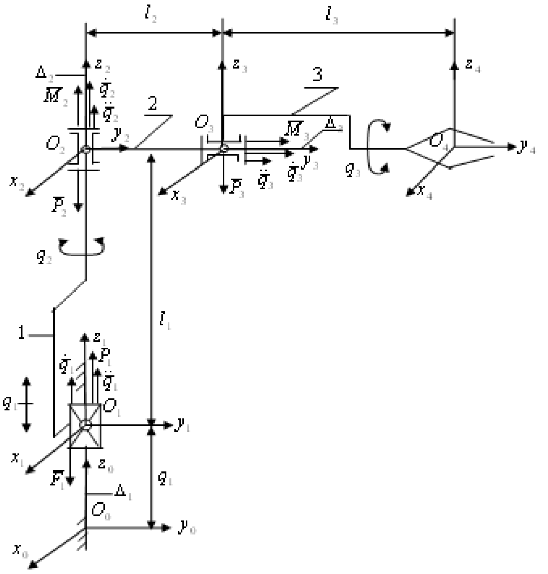


Fig. 1 Kinematic structure of the TRR industrial robot

The dynamic equations of the robot are deduced by using Lagrange's equations of type II, written as follows:

$$\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{q}_k}\right) - \frac{\partial E_c}{\partial q_k} = Q_k, k = 1,2,3, \qquad (1)$$

relation where: E_c is the kinematic energy of the robot, and Q_k stands for the generalized forces.

In the weight centres of the industrial robot modules the following Cartesian coordinates' systems are being introduced: $O_oX_oY_oZ_o$ - fixed system from the robot's base and $O_iX_iY_iZ_i, (i = 1 \div 3)$ - main systems of mobile inertia. The results are:

$$x_{ci} = y_{ci} = z_{ci} = 0, J_{xi\,yi} = J_{yi\,zi} = J_{zi\,xi} = 0. \quad (2)$$

Under these conditions, the kinematic energies, corresponding to the robot's coordinates can be consecutively obtained, starting at the robot's base:

$$E_{c1} = \frac{1}{2} m_1 \dot{q}_1^2, E_{c2} = \frac{1}{2} m_2 \dot{q}_1^2 + \frac{1}{2} J^{(2)}_{\Delta_2} \dot{q}_2^2,$$
$$E_{c3} = \frac{1}{2} m_3 \left(\dot{q}_1^2 + \dot{q}_2^2 l_2^2\right) + \frac{1}{2} J^{(3)}_{\Delta_3} \dot{q}_3^2. \qquad (3)$$

Taking relation (3) in account, the robot's total kinematic energy can be noted as:

$$E_c = \frac{1}{2}\left(\sum_{i=1}^{3} m_i\right)\dot{q}_1^2 + \frac{1}{2}\left[J^{(2)}_{\Delta_2} + m_3 l_2^2\right]\dot{q}_2^2 + \frac{1}{2} J^{(3)}_{\Delta_3} \dot{q}_3^2. \quad (4)$$

The $Q_k, (k = 1 \div 3)$ generalized forces, are obtained by giving the system elementary virtual movements so that the generalized coordinates vary in turn, respectively with the $\delta q_1, \delta q_2, \delta q_3$ elements, and the virtual elementary mechanical work δL, corresponding to the weight centres, motor forces and moments and to certain virtual elementary movements compatible with the robot's links, is:

$$\delta L = F_1 \delta q_1 + M_2 \delta q_2 + M_3 \delta q_3, Q_1 = F_1 - \left(\sum_{i=1}^{3} P_i\right), \qquad (5)$$
$$Q_2 = M_2, Q_3 = M_3.$$

The differential movement equations of the TRR robot are obtained from relation (1) where the relations (4) and (5) are introduced, consecutively giving *k* the values 1, 2, 3. The system of differential equations is set in the hypothesis that all movements of the robot are simultaneous.

Thus, the following are obtained:

$$\begin{aligned}&(\sum_{i=1}^{3} m_i)\ddot{q}_1 + m_3 l_2 \ddot{q}_2 = F_1 - (\sum_{i=1}^{3} P_i)\\&m_3 l_2 \ddot{q}_1 + (J_{\Delta_2}^{(2)} + m_3 l_2^2)\ddot{q}_2 = M_2\\&m_3 \ddot{q}_1 + J_{\Delta_3}^{(3)} \ddot{q}_3 = M_3.\end{aligned} \tag{6}$$

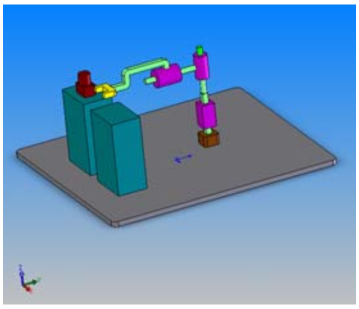


Fig. 2 3D modelling of the TRR industrial robot realized by the Solid Works soft

3. SETTING THE MOTOR MOMENT NECESSARY FOR TAKING INTO SERVICE THE MO-1 ORIENTATION MOBILE EQUIPMENT

By using the last two relations of set (6), related to the two rotation modules of the studied robot and by imposing numerical values for the optimal functioning of the MO-1 orientation module which owns two liberty degrees (rotations of the TRR robot) in the organological structure, we can determine the motor moments, respectively the servomotors for operating the MO-1 mobile equipment, staring at the designed module's organology. Hence, the expressions of M_2 and M_3 function of the MO-1 orientation module construction are:

$$\begin{aligned}&M_2 = \frac{30}{\pi} \bullet \frac{P_2}{n_2}, n_2 = n_{m2} \bullet \frac{z_1'}{z_2'} \bullet \frac{z_3'}{z_4'},\\&P_2 = P_{nm2} \bullet \eta_{r1}' \bullet \eta_{12}' \bullet \eta_{r2}' \bullet \eta_{34}' \bullet \eta_{r3}'\\&M_3 = \frac{30}{\pi} \bullet \frac{P_3}{n_3}, n_3 = n_{m3} \bullet \frac{z_1}{z_2} \bullet \frac{z_3}{z_4},\\&P_3 = P_{nm3} \bullet \eta_{r1} \bullet \eta_{12} \bullet \eta_{r2} \bullet \eta_{34} \bullet \eta_{r3},\end{aligned} \tag{7}$$

where the following notations were made: η_{r1}', η_{r1} - the output of a pair of radial bearings, η_{12}', η_{12} - the output of the cylindrical, respectively cone-shaped, gearing, , η_{r2}', η_{r2} - the output of the axial radial bearings from the rotation axis II, and VI, η_{34}', η_{34} - the output of the cone-shaped gearing, η_{r3}', η_{r3} - the output of the pair of radial-axial bearings from the rotation axis III, and VII, $z_1', z_1 \div z_4', z_4$ - the number of the gearing's grinders used for building the MO-1 module, $\frac{z_1'}{z_2'} \div \frac{z_3}{z_4}$ - the reports of the gearing's transmission from the MO-1 module's organological structure. Afterwards, the M_2, respectively M_3, motor moments for operating the MO-1 module are determined, considering the differential movement equations of the robot and the organology of the projected mobile equipment:

$$\frac{P_{nm2}}{n_{m2}} = \frac{\pi \bullet \frac{z_1'}{z_2'} \bullet \frac{z_3'}{z_4'}}{30 \bullet \eta_{r1}' \bullet \eta_{12}' \bullet \eta_{r2}' \bullet \eta_{34}' \bullet \eta_{r3}'} \bullet$$

$$\bullet [m_3 l_2 \ddot{q}_1 + (J_{\Delta_2}^{(2)} + m_3 l_2^2)\ddot{q}_2],$$

$$M_{m2} = 9550 \bullet \frac{P_{m2}}{n_{m2}} [Nm], \qquad (8)$$

$$\frac{P_{m3}}{n_{m3}} = \frac{\pi \bullet \frac{z_1}{z_2} \bullet \frac{z_3}{z_4}}{30 \bullet \eta_{r1} \bullet \eta_{12} \bullet \eta_{r2} \bullet \eta_{34} \bullet \eta_{r3}} \bullet$$

$$\bullet (m_3 \ddot{q}_1 + J_{\Delta_3}^{(3)} \ddot{q}_3),$$

$$M_{m3} = 9550 \bullet \frac{P_{m3}}{n_{m3}} [Nm].$$

By entering numerical values, we will obtain:

$$M_{m2} = 1{,}623[Nm], M_{m3} = 1{,}362[Nm] \Rightarrow$$

$$M_{m2,3} STAS = 3{,}25[Nm],$$

And, from the catalogue, we will choose the continuous flow Merkes MH2 operation servomotor (see fig. 3), equipped with TIRO and features from the catalogue.

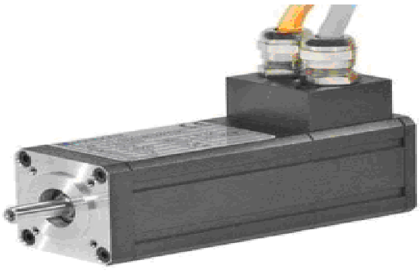
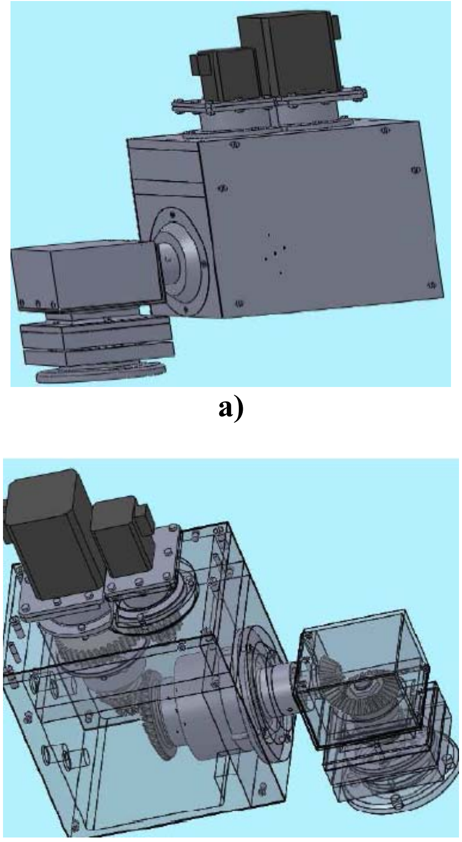


Fig.3 MH3 catalogue operation servomotor

4. THE FUNCTIONING AND CONSTRUCTION OF THE MO-1 PREHENSION DEVICE'S ORIENTATION MODULE

Figure 4 displays the constructive version of the prehension device's orientation module with two liberty degrees and, taking this figure into consideration the main components of the module can be identified. Thus, the MO-1 module contains the following constructive elements: operation motors, coupling, motor support spares, radial-axial roll bearings, respectively axial ball bearings, on one row, cone-shaped gearing from the rotation axis 1, cylindrical gearing, respectively cone-shaped from the rotation axis 2, input shaft (rotation axis 2), prehension device clamping element, satellite-holding bar, intermediate shaft, exterior casing of the module, input shaft (rotation axis 1).



a)

b)

Fig. 4 MO-1 prehension device's orientation module: a) 3D model; b) section in module

The projection of the MO-1 orientation module has been realized based on calculus prescriptions by using the Solid Works soft. Further on, the functioning on the two rotation axes of the rotation module will be presented. The two rotation movements of the directed element on which the clamping device is mounted are featured by the *n1* and *n2* revolutions. Operating the first continuous flow motor, the cone-shaped gearing is taken into movement, hence obtaining at the module output the *n1* revolution. By operating motor 2, the movement gets to the satellite-holding bar by means of the cylindrical gearing and the cone-shaped one. Hence, a rotation movement with the *n2* revolution of the prehension device and a rotation movement of the latter are obtained. In order to obtain high positioning precisions, the used motors are equipped with TIRO-type transcribers. In conclusion, we can state that the usage of electrical operations on orientation modules from the mechanical structure of modular construction robots and of cylindrical and cone-shaped gear decelerator, leads to compact constructions, with reduced gauge and minimal energy consumptions.

5. CONCLUSIONS & ACKNOWLEDGMENT

The serial manufacturing of a large number of industrial robots with various architectural versions, performing in different-shaped and different-dimensioned workspaces, according to the manipulation programme requirements, can be realized by conceiving models of modular-structured robots. The modular conception is based on the individual achievement of modules of which construction allows their assembly with other modules. Thus, we obtain varied industrial robots' architectures, which can be delivered to beneficiaries in compliance with the criteria of the actual application.

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