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Contributions to calculus, designing, modeling and constructive optimization of a rotation module from the base of an articulated robot

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Abstract. The authors of the presented paper are propose to relief the calculus, modeling and construction of the rotation module from the base of an articulated industrial robot (MRB) which possess in his cinematic chain three degrees of freedom, type RRT. It is propose a choosing variant of the direct current driving engine of the rotation module, knowing the output momentum and calculating the input momentum. This is realized by equalize of an equation which results from dynamic modeling of the robot with a designing equation which keep in view the component elements of the structure of the module.

1. Introduction

The robot represents a manipulator, multipurpose reprogrammable, for displacement of materials, parts, tools or equipments, through motions variable programmated, in goal to realize different loads (technological operations). The robot can, also, represent an equipment with automated function, adaptable to the conditions of a complex environment in which the robot evaluate through programming, succeeding to prolog, to amplify and to substitute one or more from the human functions from the environment.

2. The conception, calculus and designing of the rotation module from the robot's base type RRT-MRB

The mechanical structure of the industrial robots has to congregate a lot of requirements like:

- constructive versatility;
- minimal energy consumptions;
- to insure the rigidity and increasingly driving accuracy;
- stabilization of an structure to the action of the extern factors;
- to ensure the protection of the worker.

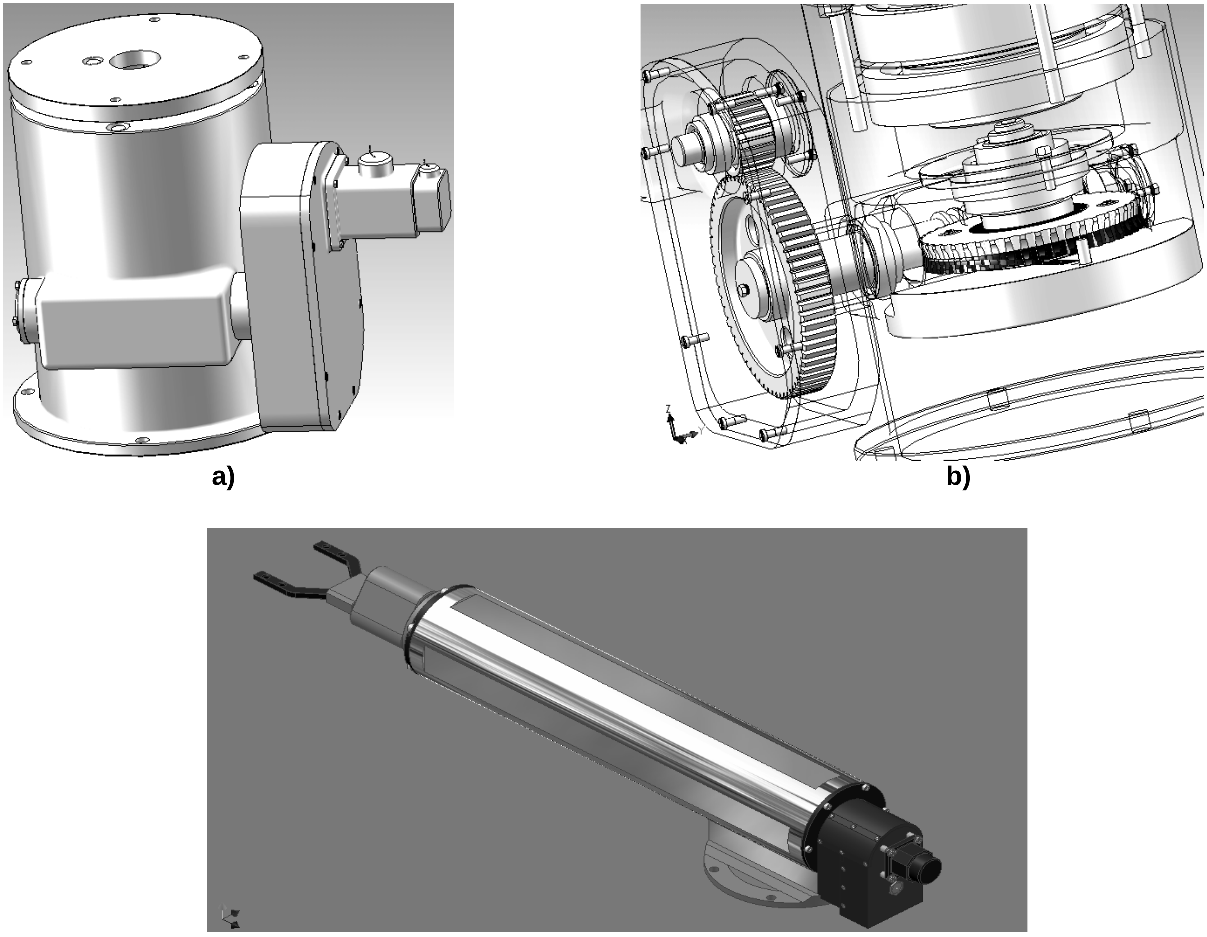
In order of their relative emplacement, going from the base to the last module in the structure of the robot can be cinematic joints which belong to three mechanisms: trajectory generator mechanism, orientation mechanism and the clamping device, the mobile elements of this having, beside the functional roll the realization of the motions and the functional roll to support and to fixation of other cinematic joints from his surety.

According to the load and the environment that the robot was designed, the modules from the base of the robot can be rotation modules or translation modules (for long or short process). The module from the robot base is the first functional module, in addition to layer or the carriage over which is mounted the robot. This module has the most powerful static and dynamic charge.

The rotation module from the base of the robot is the first functional subassembly, this confer the first degree of freedom, generally the rotation after axis Oz, concurrently being the support of the other functional mechanisms of the robot.

The rotation and translation modules from the mechanical structure of the manipulators and industrial robots can be electric, hydraulic, pneumatic or combined actuated. The construction of the rotation and translation modules is dependence on the actuating way and the engine type which can be oscillatory, rotary or linear.

In construction of the rotation and translation modules and of the clamping devices from the industrial robots structure is frequently used ball, roller or combined screws, in virtue of the advantages of this mechanisms, like: the miniaturization of the construction, transmission of the big torques, high accuracy of the motion transmission, high effective power, etc.



a) **b)**

c)

Fig. 1 a), b) The rotation module from the base of the robot MRB; c) the translation module of the clamping device MT-Sil

The rotation module from the robot base from figure 1 a) and b) has the next function principle: from the direct current electrical engine the motion is transmitted to the rolled nut, unitive with worm gear through a spur gear and worm gearing. The nut being axial locked, transmit the motion of the combined screw which, can rotate because of splines from the end of the screw, effectuate a translation motion along of his axis. The motion, thus, will get to the ball nut which is unitive with mobile equipment of the module, axial locked through bearings.

Thus, the translation motion of the combined screw is transformed in rotation motion of the circular plate through the nut. The rotation motion is recorded from the output element by a position transducer build-in a servomotor, through spur gear.

In point of the calculus of the mechanism combined ball and rolled screw-nut it is on record the next aspects:

The maximum axial force F_{am} which have to satisfy the next condition:

$$F_{am} \le F_c, \tag{1}$$

where, F_c represent the critically buckling load.

The critically buckling load is calculated with formula:

$$F_c = 34000 \cdot \frac{a \cdot d_1^4}{l_s^2} \quad [N], \tag{2}$$

where: $a-$represent coefficients which keep sight of the bearing type (it is adopted the value $a = 2$ because the bearing is rigid on one extremity and simply supported to the other extremity); d_1- represent the interior diameter of the screw, in [mm], and $l_s -$is the unsupported length of the screw, in [mm].

The ratio $\frac{l_s}{d_1}$ has to verify the relation $\frac{l_s}{d_1} < 50$.

The medium axial force is determined with next formula:

$$F_{am} = \left(\frac{F_d^3 \cdot n \cdot p}{n_m} \right)^{\frac{1}{3}} [N], \tag{3}$$

where: F_d $-$represent the acting axial force on screw, in [N]; $n-$the speed corresponding to the force F_d, in $\left[\min^{-1}\right]$; $p-$percentage of application in time of the force F_d in a working cycle (p=25%), and n_m $-$is the medium speed, in $\frac{rot}{\min}$.

$$F_d = \left(\sum_{i=1}^{3} m_i \right) \cdot g \quad [N]; n = \frac{\dot{q}_1 \cdot 1\left[\frac{rot}{s}\right]}{p_h} \cdot 60 \left[\frac{rot}{\min}\right]; n_m = n \cdot p \quad \left[\frac{rot}{\min}\right]. \tag{4}$$

In conclusion it is satisfy the condition $F_{am} \le F_c$.

The coefficient of elasticity for the nut is calculated with the next formula:

$$E_0 = \frac{E}{1 - \frac{1}{m^2}} = 2{,}307 \left[\frac{N}{mm^2}\right], \tag{5}$$

where, $E-$represent the coefficient of elasticity, and $m-$represent the Poisson's coefficient for steel. The maximum speed admissible has to regard the nest relation:

$$n_a \le 0{,}8 \cdot n_c \quad \left[\min^{-1}\right], \tag{6}$$

in which, n_c represent the critical speed and it is calculated with next relation:

$$n_c = 402 \cdot 10^5 \cdot b \cdot \frac{d_1}{l_s^3} \left[\min^{-1}\right]. \tag{7}$$

The torque necessary to rotate the screw is calculated with formula:

$$M = \frac{P_h \cdot F_{am}}{2 \cdot \pi \cdot \eta} \cdot 10^{-3} \quad [N \cdot m], \tag{8}$$

where, η represent the effective power of the transmission screw-nut and is deduced with the next relation:

$$\eta = \frac{1}{1 + 0{,}02 \cdot \frac{d_0}{p_h}}. \tag{9}$$

Had been adopted the next numerical values:

$d_1 = 24.6\ [mm];\ l_s = 550\ [mm];\ m_1 = 44\ [Kg];\ m_2 = 40{,}41\ [Kg];\ m_3 = 7{,}72\ [Kg];$

$g = 9{,}81;\ \dot{q}_1 = 0{,}75\ [rad/s];\ p_h = 0{,}008\ [mm];\ E = 2{,}1 \cdot 10^{-5}\ [N/mm^2];\ m = \frac{10}{3};\ b = 3{,}4\ [mm];$

$d_0 = 24{,}6\ [mm].$

3. The dynamic calculus regarding the choosing of the driving engine attached to the module MRB

Using the Lagrange's equations of second kind written under the next form:

$$\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{q}_k}\right) - \frac{\partial E_c}{\partial q_k} = Q_k,\ k = 1 \div h, \tag{10}$$

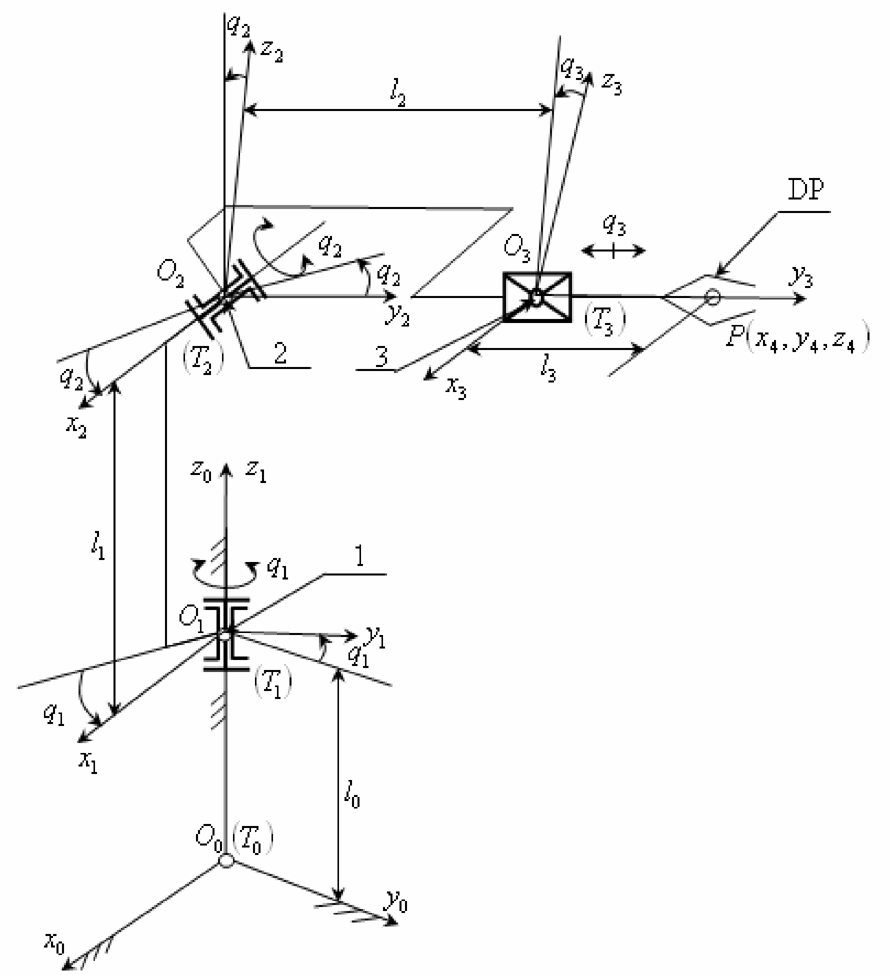


Fig. 2 The cinematic scheme of the robot RRT

and applying these equations on the studied robot in the direct dynamical modeling is obtained the differential equation of motion corresponding to the rotation module from the base of the robot MRB:

$$\left[J_{\Delta_1}^{(1)} + J_{\Delta_1}^{(2)}\right] \cdot \ddot{q}_1 = M_1, \tag{11}$$

where: $J_{\Delta_1}^{(1)}, J_{\Delta_1}^{(2)}$ – represent the mechanical momentum of inertia of the mobile equipment of the rotation module, respectively of the orientation module, in regard to the rotation axis (Δ_1); $\ddot{q}_1$ – represent the angular acceleration on output corresponding to the rotation module; M_1 – the output torque corresponding to the rotation module.

The torque M_{m_1} available to the axis of the combined screw with balls and roller can be determinate with relation:

$$M_{m_1} = 9550\frac{P_s}{n_s}\ [N \cdot m], \tag{12}$$

where, P_s, n_s represents the power, respectively the speed generated by the combined screw.

Having in view the construction of the rotation module and of the combined screw can be expressed the power P_s and the speed n_s thus:

$$P_s = P_m \cdot \eta_c \cdot \eta_r \cdot \eta_m \cdot \eta_s, \quad [kW]; \qquad n_s = \frac{n_m}{i_c \cdot i_m \cdot i_s}, \ \left[\frac{rot}{\min}\right], \tag{13}$$

where: P_m, n_m – represent the power, respectively the speed of the direct current engine which actuate the rotation module; $\eta_c, \eta_r, \eta_m, \eta_s$ – represent the effective power of the spur gear, of one pair of bearing, of the worm gear and of the combined screw; i_c, i_m, i_s – represent the gear ratio corresponding to the spur gear, worm gear and the combined screw.

Having in view the relations (13), the relation (12) becomes:

$$M_{m_1} = 9550 \cdot \frac{P_m \cdot \eta_c \cdot \eta_r \cdot \eta_m \cdot \eta_s}{n_m} i_c \cdot i_m \cdot i_s. \tag{14}$$

The differential equation of motion (11), having in view the relation (14), will have the next form:

$$\left[J_{\Delta_1}^{(1)} + J_{\Delta_1}^{(2)}\right] \cdot \ddot{q}_1 = 9550 \cdot \frac{P_m \cdot \eta_c \cdot \eta_r \cdot \eta_m \cdot \eta_s}{n_m} i_c \cdot i_m \cdot i_s, \tag{15}$$

thus resulting the ratio between the power and the speed of the direct current engine:

$$\frac{P_m}{n_m} = \frac{\left[J_{\Delta_1}^{(1)} + J_{\Delta_1}^{(2)}\right] \cdot \ddot{q}_1}{\eta_c \cdot \eta_r \cdot \eta_m \cdot \eta_s \cdot i_c \cdot i_m \cdot i_s \cdot 9550}. \tag{16}$$

Knowing the ratio $\frac{P_m}{n_m}$ is deduced the torque of the direct current engine with next relation, obtaining the value of this:

$$M_m = 9550\frac{P_m}{n_m} \Rightarrow M_m = 4{,}627\ [N \cdot m]. \tag{17}$$

Knowing the calculated torque is choosing from the catalogue DREHSTROMMOTOREN the engine type A0441BSM90N with conventional torque $M_{m_{STAS}} = 4{,}3\ [N \cdot m]$ and having build-in the transducer type A044/FDH4A10TR-RN20.

Had been adopted the next numerical values:

$J_{\Delta_1}^{(1)} = 0{,}0223\ [Kg \cdot m^2]$; $J_{\Delta_1}^{(2)} = 0{,}006\ [Kg \cdot m^2]$; $\ddot{q}_1 = 1{,}5\left[\frac{rad}{s^2}\right]$; $\eta_c = 0{,}97$; $\eta_r = 0{,}995$; $\eta_m = 0{,}78$; $\eta_s = 0{,}99$; $i_c = 1$; $i_m = 30$; $i_s = 32$.

4. Conclusions

Such a robot equipped and designed can function in closed loop with a controller and can be introduced in a flexible manufacturing cell realizing with success any technological operation. Establishment of the actuating momentum of the module MRB going from a dynamic study can lead to obtaining of some optimal variants of placement of the modules in a structure of a modular or articulated robot, well and choosing of motions laws on each axis of the robot, so that the energy consumptions to be minimum.

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