

DYNAMIC MODELLING AND DESIGN OF ADAPTIVE EFFECTORS FOR MANIPULATION ROBOTS

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1. Introduction

The trends in the development of manipulation robots as a principal means for flexible automation, are primarily associated with the creation of industrial robots and manipulators for technological operations — assembly, welding, painting, monitoring etc. In this aspect, robotized structures of automation of assembly operations are being rather intensively developed. [1-6].

There exist two major directions of development of manipulation robots: [7,8]

- Synthesis and investigation of new manipulation systems,
- Synthesis and investigation of new devices designed to improve the accuracy and functional capabilities of already existing robots.

The paper deals with questions concerning the investigation of the latter trend.

To overcome the error in the relative placement of the assembled parts and performing robotized assembly, passive and active adaptive effectors are employed. The comparative analysis of these two classes shows that:

— The passive adaptive effectors have lower capabilities related to the assembly adaptiveness, but are significantly cheaper and are not affected by the environment. [1]

— The active adaptive effectors, along with the high complexity and price, offer greater possibilities of application, especially at precision joints without chamfers. [4,6]

The problems of robotized assembly are by their nature, problems of interaction robot-environment and they are characterized by nondetermined exchange of energy between the end-effector of manipulation robot and technological equipment. In such case the presentation of problems of mounting elements by assembly robots and adaptive devices from mechatronic viewpoint is performed. [8]

The mechatronic approach to solve the problem of mounting of elements consists of representation the goal function of the adaptive device as a unity of three components: (fig.1)

- scanning seeking of one component to the other;
- dynamic compliance;
- threshold feedback from the device.

The analysis and synthesis of such mechatronic devices have to guarantee realization of different trajectories of oscillation motion of the robot effector and controllability of an action in the technological cycle. In some other publications by the author was done a synthesis of adaptive effector structures and investigation of the action.

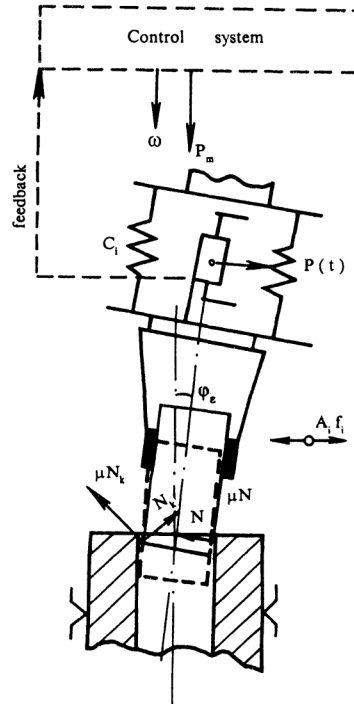


Fig. 1. A structure and action of adaptive effectors

2. Dynamic modelling of the adaptive effectors

The problems of dynamic modelling are presented in [7,8] and we note the dynamic model as separated on the main coordinates and linearized. A symmetrical structure suppose solving of axially symmetrical task to main inertia axes and elastically elements of the effectors with linearized characteristics.

In [8] the following system of differential equations of the scanning seeking motion was obtained (system (1): where: $F(t)$ – harmonic activating force; $H(t)$ — harmonic activating moment; $P_M(t)$ — controllable assembly force; F_T — a force of dry friction; μ — a coefficient of dry friction; G — weight force of system adapter -gripper- detail; A, B — mass inertia moments

of a such system; a, b, c - coordinates of elastically handling points; R_T — a radius of friction ($R_T = D_\Sigma + D/2$); D — a diameter of a hole of the basic element.

$$\begin{aligned}
 \ddot{x} + \frac{4K_x}{H}x &= \frac{F(t)}{H} \sin(\omega t) - \frac{\mu}{M}[P_M(t) + G] \operatorname{sign} \dot{x} \\
 \ddot{y} + \frac{4K_y}{H}y &= \frac{F(t)}{H} \cos(\omega t) - \frac{\mu}{M}[P_M(t) + G] \operatorname{sign} \dot{y} \\
 (1) \quad \ddot{\theta} + \frac{4(K_y c^2 + K_z b^2)}{A}\theta &= \frac{1}{A}H(t) \sin(\omega t) - \frac{\mu R_T}{A}[P_M(t) + G] \operatorname{sign} \dot{\theta} \\
 \ddot{\psi} + \frac{4(K_z a^2 + K_x c^2)}{B}\psi &= \frac{1}{B}H(t) \cos(\omega t) - \frac{\mu R_T}{B}[P_M(t) + G] \operatorname{sign} \dot{\psi}
 \end{aligned}$$

Depending of the choice of the initial conditions we will obtained respective solutions of the system (1).

For establishing regime of the resulting oscillation seeking we propose the system (2) (Solution of the system (1)), where λ is a feedback parameter.

By numerical integration with appropriately initial conditions (mass – inertia, force and metrical parameters) and application of solutions (2), we will obtain respectively trajectories, which illustrated the scanning motion through the first phase of the action. In the plane case they will be elliptical curves, Lisaju's figures, etc.

3. Interactive procedure for modelling and methodology for design

On the basis of dynamic, the solution of the direct and inverse problem (analysis and synthesis) is of a multi-variant type and it is achieved by using a personal microcomputer and creating a software module for interactive design of adaptive devices for the mechatronic mounting of the details.

$$\begin{aligned}
 X(t) &= \frac{F(t)}{4K_x - M\omega^2} \sin \omega t + \frac{\mu\lambda t}{4K_x} + \frac{\mu(P_M^H + G)}{4K_x} \\
 Y(t) &= \frac{F(t)}{4K_y - M\omega^2} \cos \omega t + \frac{\mu\lambda t}{4K_y} + \frac{\mu(P_M^H + G)}{4K_y} \\
 \theta(t) &= \frac{H(t)}{4K_\theta - A\omega^2} \sin \omega t + \frac{\mu\lambda t R_T}{4K_\theta} + \frac{\mu(P_M^H + G)R_T}{4K_\theta} \\
 \psi(t) &= \frac{H(t)}{4K_\psi - B\omega^2} \cos \omega t + \frac{\mu\lambda t R_T}{4K_\psi} + \frac{\mu(P_M^H + G)R_T}{4K_\psi}
 \end{aligned}
 \tag{2}$$

The interactive procedure (written in BASIC) was developed. The program consists of two modules — DYNCOMP and VISUAL for the calculation of the dynamic parameters of compensation (linear and angular errors) and visualization of obtained results.

On the base of the interactive procedure is developed a methodology for design of adaptive effectors, which consists of the following steps:

3.1. Calculation of the global linear and angular errors of displacement of mounting elements — on the base of error analysis we assume linear error Δ_Σ as consisting of three components: Δ_P — positioning error of assembly robot; Δ_T — error of transporting device of base element; Δ_θ — error from based mounting elements.

$$\Delta_\Sigma = \sqrt{\Delta_P^2 + \Delta_T^2 + \Delta_\theta^2}
 \tag{3}$$

We suppose the angular error of orientated elements on the range of 2 – 5 degrees.

3.2. Calculation of the total mass of the dynamic system.

$$M_\Sigma = M_a + M_x + M_\Delta
 \tag{4}$$

3.3. Calculation of the coefficients of elasticity:

$$K_x = K_y = \frac{3d^2 E}{8\pi D[2(2 + \alpha)L_n^2 + 3D^2]}; \quad K_z = \frac{Gd^4}{8D^2 n},
 \tag{5}$$

where E and G — respective modules of the linear and angular elasticity n — number of the coils; L_n — length of springs; α — coefficient of Poason.

3.4. Calculation of the mass-inertial characteristics (main inertia moments) of the dynamic system:

$$A = J_x = M(n_y^2 + n_z^2)/3; \quad B = J_y = M(n_z^2 + n_x^2)/3;$$

$$(6) \quad C = J_z = M(n_x^2 + n_y^2)/3$$

where n_x, n_y, n_z – metrical parameters of the dynamic system (approximated as rectangular body).

3.5. Assignment of the working regime by the value of circular frequency $\omega > \omega_{\text{pez}}$. (ω is frequency of the seeking)

3.6. Calculation of the parameters of the activating harmonic force $F(t)$ and harmonic moment $H(t)$. Calculation of initial value of the mounting force:

$$(7) \quad P_H^M = \mu \Delta_\Sigma K_x = \mu \Delta_\Sigma K_y$$

3.7. Examination of own frequencies values

$$(8) \quad \omega_x = \sqrt{4K_x/M}, \quad \omega_y = \sqrt{4K_y/M}, \quad \omega_z = \sqrt{4K_z/M}$$

$$\omega_\theta = \sqrt{4(K_y c^2 + K_z b^2)/A}, \quad \omega_\psi = \sqrt{4(K_z a^2 + K_x c^2)/B},$$

$$\omega_\phi = \sqrt{4(K_x b^2 + K_y a^2)/C}$$

3.8. Assignment of the initial conditions for solving of the dynamic task

$$(9) \quad q(0) = \Delta_\Sigma \phi_\Sigma; \quad \dot{q}(0) = 0$$

ω_{max} means the maximum of the working frequency

3.9. Solution of the dynamic task on the basis of (2).

3.10. Examination of the criterions:

$$(10) \quad q_i \geq \Delta_\Sigma, \quad \phi_\Sigma$$

3.11. Printing and visualization of the results.

The described methodology for design is illustrated by block-diagram – fig. 2.

The interactive procedure, numerical modelling and design were proved, based on these methodology and concrete technical assignation. The obtained main results are shown in fig. 3 (graphical appearance).

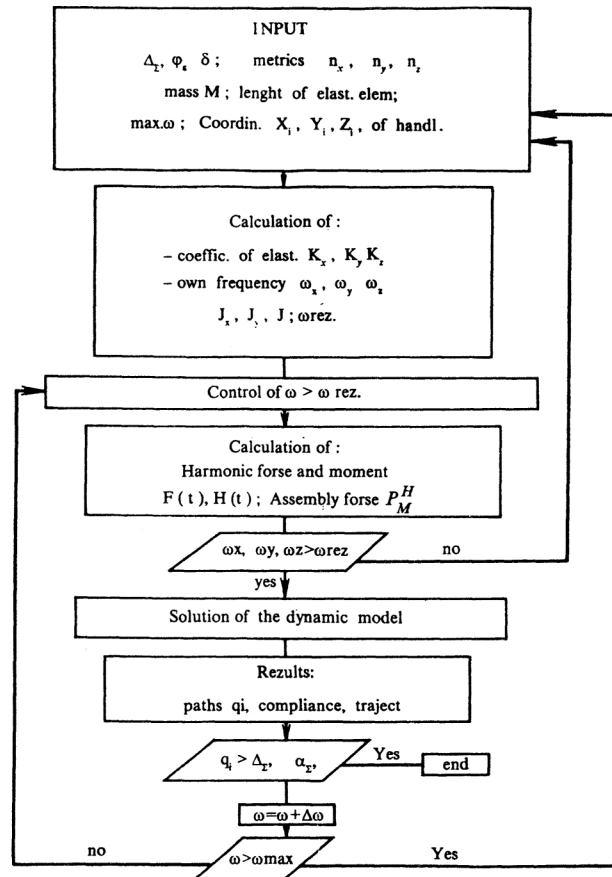


Fig. 2. An algorithm of design methodology

The procedure organizes an interactive loop of calculations on the basis of the developed dynamic models for the two-dimensional and three-dimensional case, respectively.

4. Conclusion

1) The trajectories (in plane XOY) are close curves and they illustrate the character of controllable mechanical oscillations in conditions of surface contact and significant dissipation of the dry forces.

2) The elliptical curves are very interested for practice and they are optimal for scanning seeking (it is well known, that the dispersion of the errors of the details displacement follows an elliptical law).

3) At the beginning of the scanning oscillation seeking (during the inter-

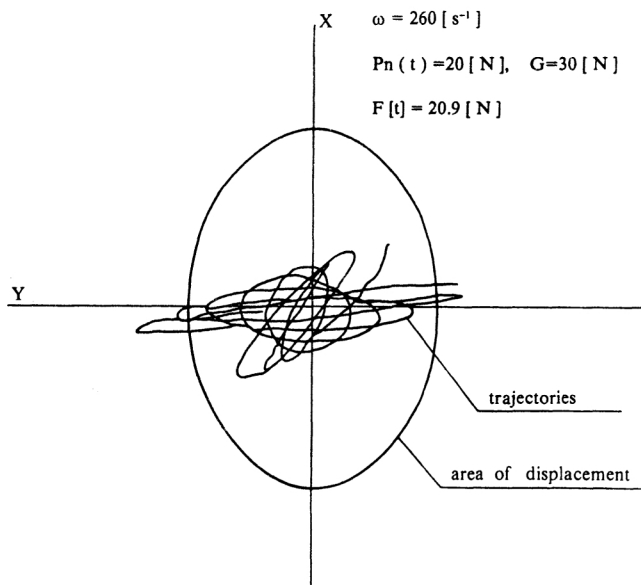


Fig. 3. Graphical results and trajectories

action of the own and force oscillations), the curves have character of Lisaju's figures and they cross the central area of displacement of the assembling axes. So, the capabilities for assembly are enlarged.

The existence of an adaptive module between the regional structure of the manipulation robot and its local structure is equal to adding more degrees of freedom to the robot, which changes its compliance and enriches its functional capabilities: manipulation, adaptiveness to changing environment conditions, etc.

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