THE MULTIPROCESSOR CONTROL SYSTEM OF DYNAMICS MULTIPLY CONNECTED TECHNOLOGICAL ELECTRIC DRIVES

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Annotation: *The problems of construction of practically realized adaptive control algorithms for interconnected electric drives with incomplete measurement of the state are considered. The certain results of industrial development of adaptive controllers for technological electric drives providing high efficiency in the conditions of the strengthened influence of parametric and vibration disturbances are reported. Models are developed for them, with the help of which the synthesis of a multiprocessor control system invariant to errors of both parametric and structural identification is carried out.*

Design and creation of multifunctional multivariable electromechanical systems (EMS) allowing to perform diverse manufacturing operations of plasma arc spraying under different influences rendered by all holonomic and nonholonomic constraints, friction forces, elastic deformations, multivariable active forces on EMS control devices require a creation of high-speed digital adaptive automatic control systems (ACS) and control algorithms for them [1, 2].

Striving to increase an accuracy and operation speed of multivariable EMS unambiguously involves an application of fast-response noncontact DC machines with a built-in position sensor and a coordinate converter. The relevance of such machines usage is determined by their linearity, structural reliability and ability to develop high torque moments in a low-speed mode which opens wide opportunities for creation of high-speed direct-drive electromechanical systems [3, 4].

The authors of the paper together with the specialists of the E. O. Paton is Electric Welding Institute (Kiev) developed and introduced into production the high-speed mechatronic module (MM) with 5 multilinked electric drives (see Fig. 1) for technological process of plasma electric-arc spraying. The multivariable mechanisms can operate in rectangular, cylindrical systems or in combinatied coordinates system [5].

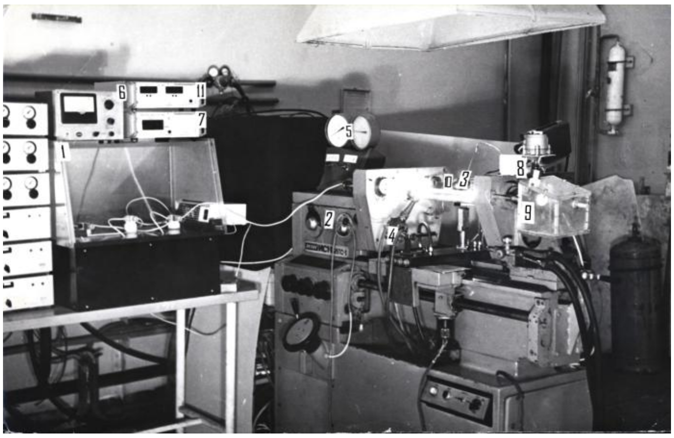

Fig. 1 Automated plasma coating device

One of the major problems encountered during the design of multivariable electric drives control systems is a restriction of dynamic parameters of the mechatronic module. This is a result of a compromise between the technical capabilities of the nodes of multivariable electric drives, physical properties of the applied materials and the performance properties of the mechatronic module (for example, minimization of the travel time or positioning time, high repeatability of the movements, etc.)

It is also necessary to consider the dynamics of multivariable electric drives actuators while constructing adaptive digital multivariable control systems. Below we consider the task of constructing and investigation the control systems of each drive of the mechatronic module with a signal adjustment according to a reference model allowing to compensate largely the dynamic effects caused by multivariable actuators arising from the joint movement of the slide assembly of plasma generator towards the movement of the work-piece.

The plasma coating equipment shown in Fig. 1 comprises the machine for plasma spraying 2, the unit of plasma-forming gas slow control 1, and the complex set of technical means of mechatronic module control system. The application of two adaptive digital control systems for rotating the work-piece and moving the slide assembly of plasma generator allows us to transfer to the next level in plasma generator control.

To implement the control laws the outer loop of each electric drive ACS contains a pulse-width position regulator selected in accordance with the requirements of a particular task. The inner high-speed loop is built as the system with the signal adjustment according to the reference model with optoelectronic speed and position sensors that transform the current position of the electric motor shaft to the appropriate voltage. The adaptive unit includes the multichannel AD converter, the adaptive interpolator and the Motorola dual-core processor MC 68302 FC20C. Having received the error signal $\Delta x(t)$ from the optoelectronic speed and position sensors concerning the model, the adaptive unit generates the adjustment signal providing the required positioning, acceleration, deceleration and stabilization algorithms.

The theory of analytical design digital controllers design using the interpolators control system can solve most of the application tasks: adaptive and modal control of electromechanical systems, optimization of actuators movement. However, in cases where it is impossible to identify coordinate and parametric perturbations in the object and to arrange a deterministic control, it is desirable to use methods of algorithmic design allowing to organize the functioning of adaptive loops based on the information accumulation about the current state of the perturbed system. One of such methods is based on the definition of Hamilton function on the movement trajectory of multivariable electric drives.

The simpliest and the most widely used in simple digital controllers way to produce discrete equations using their continuous form is not suitable for digital controllers of multivariable electric drives. The known method of discretization of continuous differential equations by replacing the differentiation operation with simple difference does not provide a high accuracy of differential vector-matrix equations at low quantization frequencies. Further one of possible well developed methods of obtaining such equations based on discretization of continuous linear equations of digital controller is considered. It represents a generalization of discretization method using a transition matrix of the control object for a nonstationary case and an apparent dependence of the vector coordinates observation on control and a range of process noise. The system of vector-matrix differential equations represented in the normal form is the initial data to obtain the necessary discrete model of the control object. Assume that the algorithm of the digital controller of multivariable electric drives ACS is described by the mathematical model in the form of linearized differential equations system in the state variables [6]

$$\Delta \dot{x}(t) = A \cdot \Delta x(t) + B \cdot \Delta U(t) + F \cdot \Delta \eta(t) \ , \qquad (1)$$

and the observation equation has the form of

$$\Delta y(t) = C \cdot \Delta x(t) + D \cdot \Delta U(t) + W \cdot \Delta \omega(t) \qquad (2)$$

Here

$$\begin{aligned} &\Delta x(t) = x(t) - x_3(t) \\ &\Delta y(t) = y(t) - y_3(t) \\ &\Delta U(t) = U(t) - U_3(t) \\ &\Delta \eta(t) = \eta(t) - \eta_3(t) \\ &\Delta \omega(t) = \omega(t) - \omega_3(t) \\ &\Delta x(t) = [x_1(t), x_2(t), ..., x_n(t)]^t \\ &\Delta y(t) = [y_1(t), y_2(t), ..., y_n(t)]^t \\ &\Delta U(t) = [U_1(t), U_2(t), ..., U_n(t)]^t \\ &\Delta \eta(t) = [\eta_1(t), \eta_2(t), ..., \eta_n(t)]^t \\ &\Delta \omega(t) = [\omega_1(t), \omega_2(t), ..., \omega_n(t)]^t \end{aligned} \qquad (3)$$

where $x(t), y(t), U(t), \eta(t), \omega(t)$ – are the vectors of the state, observation, control, interference and noise, and $x^{pr}(t), y^{pr}(t), u^{pr}(t)$ - are the vectors defining the set programmed motion of the control object. The matrices A, B, F, C, D, W have dimensions $n \times n,\ n \times m,\ p \times p,\ k \times n, k \times m, 1 \times 1$ respectively. The elements of these matrices are the functions of the operating mode of multivariable electric drives, the accuracy of regulator control algorithm, the metrological characteristics of used sensors and external conditions of the regulator operation. The equations (3) are given in the physical coordinates.

While developing an interpolator, the segment is considered where the following sequence is set to $t_0 < t_1 < t_2 < ... < t_{n-1} < t_n$, where $n \in N$ and the sequence of the interpolated function values at the nodes is: $x_3(t_0) = x_3(0), x_3(t_1) = x_3(1), ..., x_3(t_{n-1}) = x_3(n-1)$, $x_3(t_n) = x_3(n)$. Then, the following can be written to describe the dynamic motion of the object controlled by the digital controller in the state space in the vector-matrix discrete representation for the closed-loop adaptive digital controller

$$\begin{cases} x_3(n) = A(t_{n-1}, t_0) \cdot x_3(n-1) + B(t_{n-1}, t_0) \cdot U(t_{n-1}) + \\ + F(t_{n-1}, t_0) \cdot \eta_3(t_{n-1}), \\ x_3(0) = const; \end{cases} \qquad (4)$$

where $x_3(n)$ – is n-dimensional state vector be the x coordinate; $A(t_{n-1}, t_0) - n \times n$ matrix of the discrete system parameters at the moment t_{n-1} for the set t_0; $B(t_{n-1}, t_0)$ – n-dimensional control vector at the moment t_{n-1} for the set $t_0, U(t_{n-1})$ – the control action; t_n – the discrete time, $t_n \in t_0 + jT_n,\ j = 1,2,...,N$, t_0 – the time characterizing the start of the pulse width regulator; T_n – the switching period of the pulse width regulator.

The solution of equations system with the variable coefficients can be written

$$\Delta x(t_n) = \Phi(t_{n-1}, t_0)\Delta x(t_0) + \int_{t_0}^{t_n} \Phi(t_{n-1}, \alpha) B(\alpha) \Delta U(\alpha) d\alpha + $$

$$+ \int_{t_0}^{t_n} \Phi(t_{n-1}, \beta) F(\beta) \Delta \eta(\beta) d\beta \ , \qquad (5)$$

where $\Phi(t, t_0)$ - is the transition matrix.

In order to transfer the to discrete time in the continuous vector-matrix equation (5), we write the solution of equations system (1), (2), (3) for the time $t_1 = i\tau$ and $t_2 = i\tau + \tau$ (τ - is the duration of one cycle of time discretization):

$$\Delta x(i\tau) = \Phi(i\tau, t_0)\Delta x(t_0) + \int_{t_0}^{i\tau} \Phi(i\tau, \alpha) B(\alpha) \Delta U(\alpha) d\alpha +$$

$$+ \int_{t_0}^{i\tau} \Phi(i\tau, \beta) F(\beta) \Delta \eta(\beta) d\beta \ , \qquad (6)$$

$$\Delta x(i\tau + \tau) = \Phi(i\tau + \tau, t_0)\Delta x(t_0) + \int_{t_0}^{i\tau+\tau} \Phi(i\tau + \tau, \alpha) B(\alpha) \times$$

$$\times \Delta U(\alpha) d\alpha + \int_{t_0}^{i\tau+\tau} \Phi(i\tau + \tau, \beta) F(\beta) \Delta \eta(\beta) d\beta \ , \qquad (7)$$

Using the property of the transition matrix:

$$\Phi(t_2, t_0) = \Phi(t_2, t_1)\Phi(t_1, t_0) \qquad (8)$$

and supposing that during one discretization interval the matrix elements A, B, F remain constant, we have:

$$\Phi(i\tau + \tau, t_0) = e^{A\tau}\Phi(i\tau, t_0) \qquad (9)$$

Then equation (7) can be rewritten as:

$$\Delta x(i\tau + \tau) = e^{A\tau}\Delta x(i\tau) + e^{A\tau} \int_{i\tau}^{i\tau+\tau} \Phi(i\tau, \alpha) B(\alpha) \Delta U(\alpha) d\alpha +$$

$$+ e^{A\tau} \int_{i\tau}^{i\tau+\tau} \Phi(i\tau, \beta) F(\beta) \Delta \eta(\beta) d\beta \qquad (10)$$

As the matrix A is constant on the interval of integration, then

$$\Delta x(i\tau + \tau) = e^{A\tau}\Delta x(i\tau) + \int_{i\tau}^{i\tau+\tau} e^{A(i\tau+\tau-\alpha)} B(\alpha) \Delta U(\alpha) d\alpha +$$

$$+ \int_{i\tau}^{i\tau+\tau} e^{A(i\tau+\tau-\alpha)} F(\beta) \Delta \eta(\beta) d\beta \qquad (11)$$

As the control vector U and variations in interference spectrum η change in a stepwise manner at each control cycle (at this time U, η values are constant), the integral in the equation (11) can be simplified to the following form:

$$\Delta x(i\tau+\tau)=\int_0^{\tau} e^{A\alpha} d\alpha B\Delta U(i\tau)+\int_0^{\tau} e^{A\beta} d\alpha F\Delta\eta(i\tau) \quad (12)$$

where:

$$\Delta U(i\tau)=U(i\tau)-U_3(i\tau)\,,\ \Delta\eta(i\tau)=\eta(i\tau)-\eta_3(i\tau)$$

Here $\Delta U(i\tau)$, $\Delta\eta(i\tau)$ – are the values of the control vector and the vector of interference spectrum at the interval $(i\tau, i\tau+\tau)$.

Proceeding to the discrete time, we obtain:

$$\Delta x(i+1)=\widetilde{A}\Delta x(i)+\widetilde{B}\Delta u(i)+\widetilde{F}\Delta\eta(i) \quad (13)$$

where

$$\widetilde{B}=(\int_0^{\tau} e^{A\alpha} d\alpha)B=\tau(A_0+\frac{A_1\tau}{2!}+\frac{A_1^2\tau^2}{3!}+...)B \quad (14)$$

$$\widetilde{F}=(\int_0^{\tau} e^{A\alpha} d\alpha)F=\tau(A_0+\frac{A_1\tau}{2!}+\frac{A_1^2\tau^2}{3!}+...)F \quad (15)$$

Similarly (13) we will get the equation for observation vector:

$$\Delta y(i+1)=\widetilde{C}\Delta x(i)+\widetilde{D}\Delta u(i)+\widetilde{W}\Delta\omega(i)\,, \quad (16)$$

Thus, the equations (13) and (16) represent the system of difference vector-matrix equations in "deviations" allowing to determine the extrapolated parameters of the actuator movement at their current values and are the basis in design of digital regulator algorithm. The process of the actuators movement is smooth. Then the Kalman filter should be used in the identifier for the coordinate estimation. Here the interference and noise vectors $\eta(t)$ and $\omega(t)$ are divided into controllable $\eta_y(t),\omega_y(t)$ and non-controllable $\eta_н(t),\omega_н(t)$. In accordance with the vectors division the corresponding separation of matrixes is conducted.

The developed adaptive control system can be easily integrated into ACS of many technological processes. The high performance of adaptive control gives an opportunity to improve the performance and reproducibility of process operations fulfillment.

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