07 - 10 September 2009

PROCEEDINGS

54. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

Information Technology and Electrical Engineering - Devices and Systems, Materials and Technologies for the Future

Faculty of Electrical Engineering and Information Technology

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=14089

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Dr. h. c. Prof. h. c.
Peter Scharff

Redaktion: Referat Marketing
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
Univ.-Prof. Dr.-Ing. Frank Berger

Redaktionsschluss: 17. August 2009

Technische Realisierung (USB-Flash-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag: isle
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilmenau

ISBN (USB-Flash-Ausgabe): 978-3-938843-45-1
ISBN (Druckausgabe der Kurzfassungen): 978-3-938843-44-4

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=14089

FORMING OF PRECISION PROGRAM MOTION IN COORDINATE SYSTEM

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ABSTRACT

The different approaches can be applied to the forming of program motion for precision coordinate systems. The structure of program motion is discussed, and the basic algorithm of precision program motion is presented. The analytical method of the forming of program motion is proposed which is built on the solving of inverse problems of dynamics.

Index Terms – Precision coordinate system, program motion, differential motion equation, inverse problem of dynamics

1. INTRODUCTION

There are different approaches for the realizing of program motions in precision coordinate systems [1, 2]. The most used among them is the approach which is built on the changing of motion parameters in according to the necessary quality of motion. For example, by accuracy – it is a position error, deviation from trajectory, amplitude or frequency of forced oscillation. Such approach is realized by follow algorithm:

a) motion program is formed preliminarily by control computer;

b) when motion is realizing, the signals of position and velocity are derived by sensors of drive measurement system;

c) obtained signals are processed by special regulation algorithms of drive control system, and the changes are included into the control action.

Regulation algorithms are based on differential equations, which need to be solved. Additionally, they are needed to carry out of the stability analysis, to find out the range of work values and so on.

Another approach can be built on analytical forming of program motion on the base of the solving of inverse problems of dynamics.

2. STRUCTURE OF PROGRAM MOTION

The problem of forming of precision motions for realization by actuating motor can be divided into four components: model, trajectory, drive and control.

Model is used for the calculation of dynamic characteristics of coordinate system, which are depended on constructive parameters, including mechanical and electrical parameters, initial state and configuration of system.

Trajectory. Actuating motor is moved on the spatial trajectory with velocities and accelerations controlled on it. Trajectory is usual corresponded to geometric lines and curves, which can be defined analytically or by set of points.

Drive. The stage (e.g. cross-table) instrument in technological equipment is set in motion by the servo drive, which controlled by personal computer via controller of control system.

Control. The control computer forms consecution of motion algorithms by the program to execute required technological operation. Then this high-level program is interpreted into the symbolic control commands, which are realized in a form of currents for phase winding of motor.

3. BASIC ALGORITHM OF PROGRAM MOTION

General structure of control of precision coordinate system is “control computer – controller – power amplifier – direct drive”. Control system can be open-loop or with feedbacks by position, velocity and acceleration.

Control computer is used for the forming of necessary control algorithms, i.e. motion trajectory in any representation. Formed trajectory is sent to drive controller, which realize it in the form of a current laws. The signal is amplified and then given directly to the windings of drive.

Using the general structure of control, scheme (basic algorithm) of forming of precision drive program motion can be proposed. The scheme is shown on Figure 1.

Step 1. Motion task is formulated in the form of analytical, graphical, table representation, or prepared in graphical software, e.g. 3D Studio Max. Then a motion task should be presented by the discrete set of points.

On this step the limitations of velocity and acceleration or the motion time can be also defined.

Step 2. Trajectory is processed into the contour or position (point to point) motion algorithm. If the position motion algorithm is used, the choosing of velocity profile are carried out (trapeziform profile is applied very often).

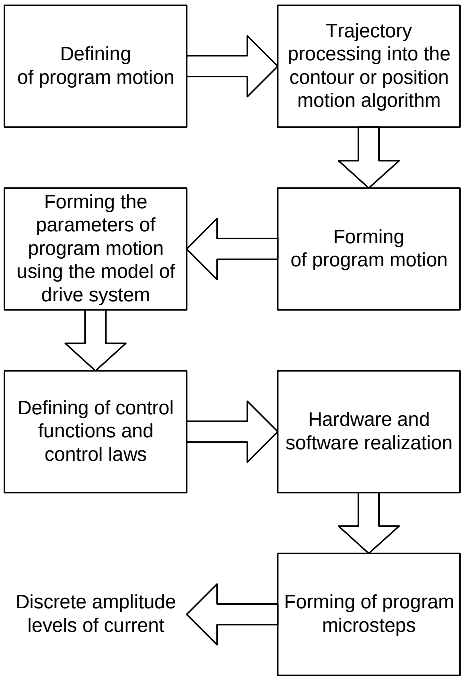

Figure 1 Basic algorithm of program motion

If the contour motion algorithm is used, the interpolation tasks are solved, velocity and acceleration functions are chosen from the condition of coupling on the boundary. Example of velocity profile is shown on Figure 2.

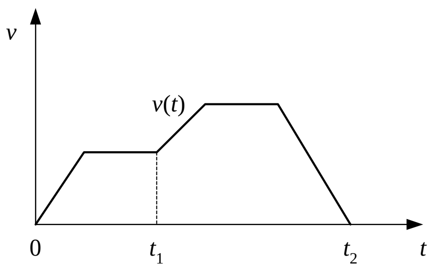

Figure 2 Example of velocity profile (contour motion)

Step 3. Forming of program motion, including the usage of internal and external feedback sensors. The main ways for it are:

– control algorithms for drive systems with feedbacks and without of them;

– algorithms, which are built on mathematical modelling and the adaptation of program motion to the physical structure of drive system and the moving object;

– forming the program motion on the method of solving of inverse task of the dynamics.

Step 4. Forming the parameters of program motion using the model of drive system.

Step 5. Defining of control functions and control laws via physical parameters of coordinate system.

Step 6. Hardware and software realization of program motions using interpolators and interpreters of controller which is based on digital signal processor.

Step 7. Forming of program microsteps in controller and giving them as amplitude levels of current into the power converter (amplifier) and then drive windings.

4. ANALYTICAL METHOD OF THE FORMING OF PROGRAM MOTION

Analytical method of the forming of program motion is based on supplementing of drive system dynamic model in accordance with analytical motion program, without solving of differential equation system. To realize this approach, model of coordinate system is needed in the form of differential equations which describe dynamic state of system in phase coordinates.

In general case equation system of one-coordinate stepping drive with m – phase winding can be written in form:

$$\begin{cases} M_\Sigma \dfrac{d^2x}{dt^2} + \beta \dfrac{dx}{dt} + F_r = F, \\ i_k r_k + \dfrac{d\psi_k}{dt} = U_k, \end{cases} \qquad (1)$$

where $k = 1, 2, \dots, m$ – numbers of electric contours which formed by phase windings of drive; i_k, ψ_k, U_k – momentary values of current, interlinkage and voltage of k-th electric contour; r_k – electric resistance of k-th contour; M_Σ – total mass of moving part of drive system; x – displacement of inductor with respect to stator; F_r – total resistance force of load and idling losses; F – electromagnetic force of drive, which defined by type and construction of stepping motor.

Similar differential equation systems can be written for any multi-coordinate system on the base of linear stepping motors [3]. Equation system (1) describes physical processes in drive system; it is full mathematical model of precision motion system.

For the aims of analytical forming of program motion, these equations of system can be resolved relatively the highest derivative and structured as

$$\ddot{x} = X_i\left(t, x_1, \dots, x_n; \dot{x}_1, \dots, \dot{x}_n\right)$$

where $X = (X_1, X_2, \dots, X_m)$ is vector of right parts of motion differential equations; $x = \left(x_1, \dots, x_n\right)$ is vector of generalized coordinates; $\dot{x} = \left(\dot{x}_1, \dots, \dot{x}_n\right)$ is vector of generalized velocities.

Then suppose, that motion features of mechanical system which is described by system (1) is determined by vector of generalized coordinates $x[x_1, \dots, x_n]$ and vector of generalized velocities $\dot{x}[\dot{x}_1, \dots, \dot{x}_n]$ which are defined in the form of integral multiformity:

$$\Omega : \omega_\mu(x, \dot{x}, t) = 0; \quad \mu = 1, \ldots, m \le n \, . \qquad (2)$$

This multiformity Ω of features of motion is essentially integral multiformity of corresponding motion equations of drive system. Thus, to solve the inverse problem of dynamics we should to build motion equation by given integral multiformity Ω so that the expressions $\omega_\mu(x, \dot{x}, t) = 0$ must be integrals of these equations. Then, we should to determine required generalized control functions (forces, parameters and correlations) from built equations, which permit the motion with given features (2).

In cases when the structure of motion equations is known but additional forces or parameters to get the motion with necessary features are unknown, we should to supplement of motion equations using the given integral multiformity and then find the control functions from supplemented equation system.

If we know only part of motion equations of considered mechanical system, to solve the inverse problems of dynamics we need to build missing motion equations using the given integral multiformity.

As result, the solving of the inverse problems of dynamics in the general mathematical statement is coming to the building of motion equations of mechanical system using the integral multiformity of motion features.

The problem of dynamics as a rule doesn't have unique solution. This fact allows solving the inverse problems of dynamics in combination with the problem of stability and optimality of motion; generally, any additional conditions and limitations to dynamic characteristics of motion can be taken into account.

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