KAUNAS UNIVERSITY OF TECHNOLOGY

Giedrius Blažiūnas

CONTROL OF MULTIFUNCTIONAL TWO-COORDINATE DRIVE SYSTEMS

Summary of doctoral dissertation

Technological Sciences, Electronics and Electrical Engineering
(01T)

Kaunas, 2005

The research was carried out during the period of 2000 to 2004 at Kaunas University of Technology.

Scientific supervisor:

Prof. Dr. Habil. Vilius Antanas GELEŽEVIČIUS (Kaunas University of Technology, Technological Sciences, Electronics and Electrical Engineering – 01T).

Counsil of Electronics and Electrical Engineering sciences trend:

Prof. Dr. Habil. Danielius EIDUKAS (Kaunas University of Technology, Technological Sciences, Electronics and Electrical Engineering – 01T) – ***chairman***,

Prof. Dr. Habil. Povilas KOSTRAUSKAS (Kaunas University of Technology, Technological Sciences, Electronics and Electrical Engineering – 01T),

Prof. Dr. Habil. Algimantas Juozas POŠKA (Vilnius Gediminas Technical University, Technological Sciences, Electronics and Electrical Engineering – 01T),

Dr. Anicetas VAIŠVILA (AB "Ekranas", Technological Sciences, Electronics and Electrical Engineering – 01T),

Prof. Dr. Habil. Arvydas VIRBALIS (Kaunas University of Technology, Technological Sciences, Electronics and Electrical Engineering – 01T).

Official opponents:

Prof. Dr. Vidas LAURUŠKA (Šiauliai University, Technological Sciences, Electronics and Electrical Engineering – 01T),

Prof. Dr. Habil. Rimvydas SIMUTIS (Kaunas University of Technology, Technological Sciences, Informatics Engineering – 07T).

The official defence of the dissertation will be held at 11.00 a.m. on 21st April, 2005, at the Council of Electronics and Electrical Engineering sciences trend public session in the Dissertation Defence Hall at the Central Building of Kaunas University of Technology (K. Donelaičio g. 73 – 403a., Kaunas, Lithuania).
Address: K. Donelaičio g. 73, Kaunas, Lithuania.
Tel.: (+370) 37 300042, fax: (+370) 37 324144; e-mail: mok.skyrius@ktu.lt

The sending out date of the summary of the dissertation is on 21st March 2005.
The dissertation is available at the library of Kaunas University of Technology.

KAUNO TECHNOLOGIJOS UNIVERSITETAS

Giedrius Blažiūnas

DAUGIAFUNKCINIŲ DVIKOORDINAČIŲ VYKDYMO SISTEMŲ VALDYMAS

Daktaro disertacijos santrauka

Technologijos mokslai, elektros ir elektronikos inžinerija (01T)

Kaunas, 2005

Disertacija rengta 2000 – 2004 metais Kauno technologijos universitete.

Mokslinis vadovas:

Prof. habil. dr. Vilius Antanas GELEŽEVIČIUS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T).

Elektros ir elektronikos inžinerijos mokslo krypties taryba:

Prof. habil. dr. Danielius EIDUKAS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T) – ***pirmininkas***,

Prof. habil. dr. Povilas KOSTRAUSKAS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T),

Prof. habil. dr. Algimantas Juozas POŠKA (Vilnius Gedimino technikos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T),

Dr. Anicetas VAIŠVILA (AB ”Ekranas”, technologijos mokslai, elektros ir elektronikos inžinerija – 01T).

Prof. habil. dr. Arvydas VIRBALIS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T),

Oficialieji oponentai:

Prof. dr. Vidas LAURUŠKA (Šiaulių universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T).

Prof. habil. dr. Rimvydas SIMUTIS (Kauno technologijos universitetas, technologijos mokslai, informatikos inžinerija – 07T),

Disertacija bus ginama 2005 m. balandžio 21 d. 11 val. viešame elektros ir elektronikos inžinerijos mokslo krypties tarybos posėdyje, kuris įvyks Kauno technologijos universitete, centrinių rūmų disertacijų gynimo salėje (K.Donelaičio g. 73 – 403a., Kaunas).
Adresas: K. Donelaičio g. 73, 44029, Kaunas, Lietuva.
Tel.: (8-37) 37 300042, faksas: (8-37) 324144, el. paštas: mok.skyrius@ktu.lt

Disertacijos santrauka išsiųsta 2005 m. kovo mėn. 21 d.
Su disertacija galima susipažinti Kauno technologijos universiteto bibliotekoje.

INTRODUCTION

Multidimensionality is the essential feature of modern technological systems. In these systems it's demanded to coordinate the motions of drives, ensuring maximum productivity of technological processes and saving energy, equipment resources. Multi-coordinate and two-coordinate drive systems are usually met in systems of multi-dimensional and two-dimensional objects positioning and contouring. In case of two-dimensional positioning end-device or object has to be transported from initial to final space point, regardless of motion trajectory. The typical application of positioning – pick & place operation. Meanwhile in contouring systems the en-device is moving according the defined motion trajectory. In this case the examples of welding, cutting and painting could be mentioned. All these systems are the part of two-coordinate drive systems, which are widespread group of multi-dimensional drive systems.
Integration of modern mechatronics in drive technology gives opportunity to implant flexible control algorithms for realization of various technological functions. In common meaning by increasing functionality of drive systems and saving energy, equipment resources, the problem of saving global material resources is solved as well. This problem becomes extremely substantial in circumstances of intensively increasing production and consumption.
Still the problem of saving resources hasn't got the highest priority in context of requirements for two-coordinate drive systems. In many cases two-coordinate drive systems have the task to insure positioning quality. This is described by static accuracy. The second high priority problem, which has to be solved by two-coordinate drive systems, is optimal rapidity.
The equipment rapidity is conditioned by maximal allowable positioning speed and acceleration. In many cases these parameters are to be limited according to technical abilities of particular drive systems. While working with maximum forces and torques, equipments face the problem of rapid wear.
Consequently development of control methods for two-coordinate drive systems is very important in nowadays industry. The large contribution toward developing electromechanical drive systems is already done by Lithuanian scientists: V. Geleževičius, K.Kriščiūnas, V. Barzdaitis, S. Kaušinis, A. Poška, A. Smilgevičius, V. Babkaitis.
Although two-coordinate drive systems aren't novelty, there are no presented control methods that increase the multifunctionality of such systems and solve the problem of saving and rational handling of global material resources.

The research object is to develop and investigate methods and algorithms for flexible control of two-coordinate drive systems. Appling developed control methods, the problems of saving and rational handling of energy, equipment and global material resources have to be investigated in cases of two-dimensional positioning and scanning processes under circumstances of maximal rapidity.

The following problems are solved:

- The investigation of the tasks and control systems of two-coordinate positioning and scanning processes according to special requirements – guarantee defined accuracy and maximal productivity of system, save energy, equipments resources.
- The development of multifunctional two-coordinate drive system structure, which enables to solve different control task in two-dimensional space using the unique hardware.
- The development of the model, which enables to analyze functionality and stability of multifunctional two-coordinate drive system.
- The investigation and development of control methods for solving and coordination of different tasks (two-coordinate positioning, scanning).

Scientific novelty

The main points of scientific novelty of this work are:

- Control principles, that allow multifunctional two-coordinate drive system to solve functionally different control problems (two-coordinate positioning and scanning), related by common control objectives – guarantee demanded accuracy, maximal rapidity and save equipment's and energy resources.
- Control methods and means, affording to create multifunctional, multipurpose two-coordinate positioning – scanning system, which guarantee demanded accuracy of positioning, scanning processes, save equipment's and energy resources under the conditions of maximal rapidity.
- Multi-agent control system, which allows solving multifunctional tasks of two-coordinate drive system and together dealing with coordination and control problems.

Practical value

The main practical feature of multifunctional two-coordinate drive systems is possibility to realize functionally different positioning and scanning control tasks, leaving untouched hardware of the system. The proposed control methods ensure two-coordinate drive system to solve last-mentioned control tasks and meet specific requirements: guarantee demanded quality, rapidity of overall process, increase durability of equipment and power efficiency. The work results will help to solve both technical and economical, ecological design, maintenance problems of multifunctional two-coordinate drive system.

The items presented for defence:

- The control principals that enables to solve different two-dimensional problems for two-coordinate drive systems.

- Control methods and means, which allow developing multifunctional two-coordinate positioning-scanning system.
- Multi-agent control system, which allows solving multifunctional tasks of two-coordinate drive system.

Approbation and publication of the work
The results of the research have been presented at the scientific conferences, namely:

1. Automation and Control Technologies – 2001, Kaunas, Lithuania, 2001.
2. Electronics – 2001, Kaunas, Lithuania, 2001.
3. Electronics – 2002, Kaunas, Lithuania, 2002.
4. 10th International Conference on Power Electronics and Motion Control, Cavtat & Dubrovnic, Croatia, 2002.
5. Electronics – 2003, Kaunas, Lithuania, 2003.
6. International Conference on Control Applications, Istanbul, Turkey, 2003.
7. Electronics – 2004, Kaunas, Lithuania, 2004.
8. Automation and Control Technologies – 2004, Kaunas, Lithuania, 2004.

The material of the research report was presented in 8 publications.

Structure and volume of the dissertation
Dissertation consists of an introduction, five chapters, and conclusions, list of references and list of author's publications. Total volume of dissertation is 114 pages, 57 illustrations and 13 tables.

1 MULTIPURPOSENESS AND MULTIFUNCTIONALITY OF TWO-COORDINATE DRIVE SYSTEM

The first chapter overviews specific requirements and problems that deal with control of two-coordinate drive systems. The possibilities of saving resources in two-coordinate drive systems are discussed as well.
From literature review it could be maintained that main control tasks for two-coordinate drive systems are:

- two-coordinate positioning;
- scanning in two-dimensional space;
- two-dimensional contouring.

Every control task realizing system has to match specific requirements:

- guarantee demanded accuracy of system;
- guarantee maximal rapidity;
- optimally use energy and equipment's resources.

In case of two-coordinate positioning there are three control tasks to guarantee: demanded accuracy of both drives; maximal productivity of process; resources saving. Overall accuracy of two-coordinate system is conditioned by steady-state accuracy. For realization of this control task astatic control system has to be used. Overall process productivity is conditioned by rapidity of drives. For this purpose it's necessary to use principals of optimal rapidity. For solving of the third – resources saving – control task special control methods of two-coordinate drive system are used. The highest priority purpose is to guarantee demanded accuracy of the system. After solving of this control problem the second order problem could be solved and etc.

In case of two-dimensional scanning there are also three purposes:

- guarantee stability of velocity of shuttle drive and accuracy of stepping drive;
- guarantee productivity of scanning process;
- save equipment's and energy resources.

From defined purposes there could be marked two of them, because productivity of scanning process depends on specifics of technologic process. The highest priority is given to the task of system quality. If stability of velocity of shuttle drive and accuracy of stepping drive were guaranteed, the purpose of resources saving could be solved. In case of contouring control all purposes form one common control task – guarantee dynamic accuracy of drives. Process productivity and minimization of power loss depend on specifics of technologic process.

Given review concludes that multipurpose control tasks can be considered as the tasks of two-coordinate positioning and two-dimensional scanning.

The control problem of two-coordinate positioning is divided into three partial control problems that are characterized by function:

$$\mu = \begin{cases} -\xi < \forall\Delta = \left|\Delta X_{11N}\right| - \left|\Delta X_{21N}\right| < \xi, \\ \forall\Delta = \left|\Delta X_{11N}\right| - \left|\Delta X_{21N}\right| > \xi, \\ \forall\Delta = \left|\Delta X_{11N}\right| - \left|\Delta X_{21N}\right| < -\xi, \end{cases} \quad (1)$$

In first partial problem referred displacements of both drives are equal ($\Delta X_{11N} = \Delta X_{21N}$), both drives act independently. The second partial problem describes the case where referred displacement of the first drive is larger than displacement of second one ($\Delta X_{11N} > \Delta X_{21N}$), the first drive acts as master drive, second – as slave. In the third case of two-coordinate positioning referred displacement of the second drive is larger than displacement of the first drive ($\Delta X_{11N} < \Delta X_{21N}$), the second drive acts as master drive, the first – as slave drive.

The control problem of two-coordinate scanning is divided into two partial control problems. In case of the first partial control problem of scanning process the first drive makes shuttle movement, the second – movement of appropriate size step. The second control problem describes reverse case: the first drive becomes stepping, the second – shuttle drive.

Though all five partial control problems have their own control specifics and are characterized by own functional diagrams, they can be realized using universal structure, presented in Fig.1. The given structure of two-coordinate drive system consists of two stable velocity control systems (*GRS)* that are formed using principals of maximal rapidity. Since the block of velocity control system can be found in every industrial drive no matter what kind of actuator is used, multifunctional two-coordinate drive system can be developed by means of these drives and nowadays control devices.

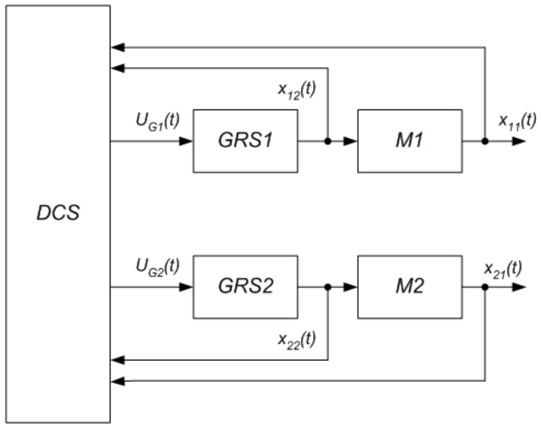

Fig. 1. Universal structure of two-coordinate drive system

This chapter introduces review of control systems that are used for drive control. It could be mentioned that different types of control principals are used for mono or due duo drive control. In some applications there were used classical regulators with multi-feedback control, adaptive control systems with observers, fuzzy or neuron network systems. When number of end-devises, control tasks or modes increases, the problems of system configuration, coordination appears. For these control problems agents and multi-agent control systems are used.

For realization of control system of two-coordinate positioning and scanning tasks the method of agents and multi-agent control systems was chosen with the purpose to solve the problems of coordination of different control tasks.

2 STABILITY ANALYZES AND MODELLING OF MULTIFUNCTIONAL TWO-COORDINATE DRIVE SYSTEM

This chapter deals with stability analyzes of basic structure of two-coordinate drive system. The design strategy of quasi-real time model for simulation of two-coordinate drive system is proposed.

Stability analyzes of basic structure

Stability analyzes were carried out to find out the stability reserve of two-coordinate drive system acting in positing mode when velocity signal for slave drive is formed from two signals: actual velocity of master drive and referred velocity formed at the output of position regulator.
Stability of the system is determined from eigenvalues of closed loop z-transfer function (2). If all eigenvalues of (3) expression are $|\eta_l| < 1, \forall l$, the system is stable.

$$G(z) = \frac{b_{n-1}z^{n-1} + b_{n-2}z^{n-2} + \dots + b_1 z + b_0}{z^n + a_{n-1}z^{n-1} + \dots + a_1 z + a_0}. \quad (2)$$

Eigenvalues are derived from expression:

$$\det(\eta I - A_d) = 0 , \quad (3)$$

where

$$A_d = \begin{bmatrix} 0 & 1 & 0 & \dots & 0 & 0 \\ 0 & 0 & 1 & \dots & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ -a_0 & -a_1 & -a_2 & \dots & -a_{n-2} & -a_{n-1} \end{bmatrix}. \quad (4)$$

Stability analyzes showed that multifunctional two-coordinate drive system, which is described by two identical velocity systems ($H_{GRS}(s) = 10 / (0.008s^2 + 0.04s + 1)$) and mechanical joints ($k_M = 0.1$), has sufficient reserve of stability, if sampling time lies in the range of 0.01 … 0.001 s.

Quasi-real time model

The structure of model of two-coordinate drive system is divided into two parts in dependence of means of practical realisation. The part of control system, which is foreseen for realisation by software means, may be modelled directly by corresponding program written specially for this case. After investigation this program can be implemented as real control program of system. Other part of system representing its hardware can be digitally modelled on the base of *z* transfer function of its analogous part.
Taking in account the computing capacity of modern industrial computers it is purposeful to charge the computer with all-necessary regulation and logical control functions. So the hardware is to be charged only with power conversion by electrical (pneumatic, hydraulic) drives functions, ensuring necessary quality of motions performance. Fig. 2 illustrates this concept.

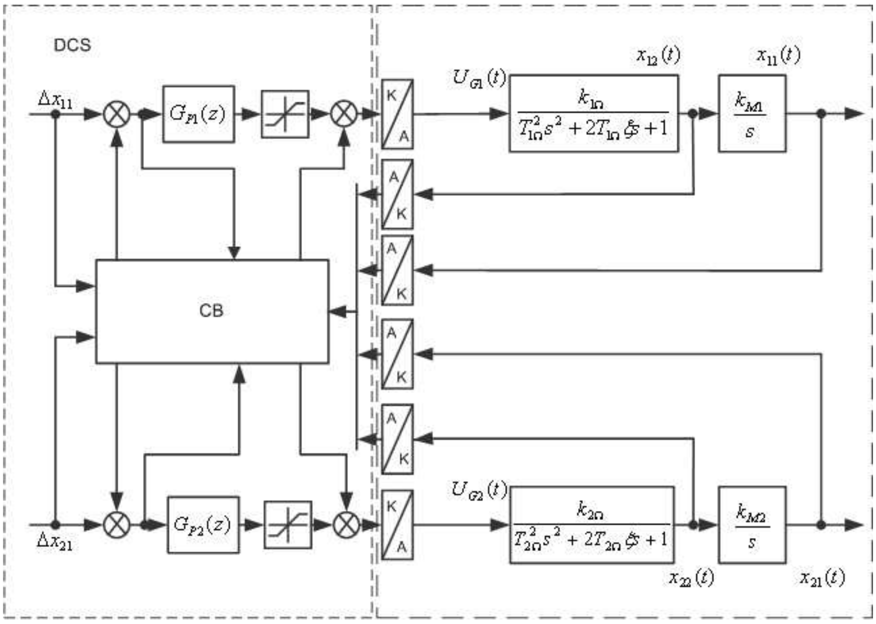

Fig. 2. Model structure of two-coordinate drive system

Model program parts representing both software and hardware parts of real system communicate between each other in the same way as the computer in practical realisation communicates with hardware of the controlled system. It means that:

- Control data obtained on the outputs of numerical controller has to be sent to inputs of velocity control systems trough gates simulating D/A converters and allowing only integer format of data representation;
- Information about process is to be sent back to the controller trough gates simulating A/D converters i.e. also allowing integer format of data representation;
- Data changes must take place in real time mode, therefore it has to be synchronised by clock;
- Data sampling time of model is to be adequate to data sampling time of future digital control system.

Modeling results

The digital modelling of the system took place using the following set of parameters: values of proportional P regulators - k_{11} =1.6, k_{12} =1.6; gain of mechanical joint - k_{mj}=1; gain of speed control system - k_{Ω}=5; time constant - T_{Ω}=0.04s. The time constant T_{Ω} corresponds to the rapidity of real industrial electrical drives. It was assumed that incremental encoder standing on the motor shaft gives 100000 increments per 1 revolution and displacement feedback ratio is equal: k_d = 0.001.

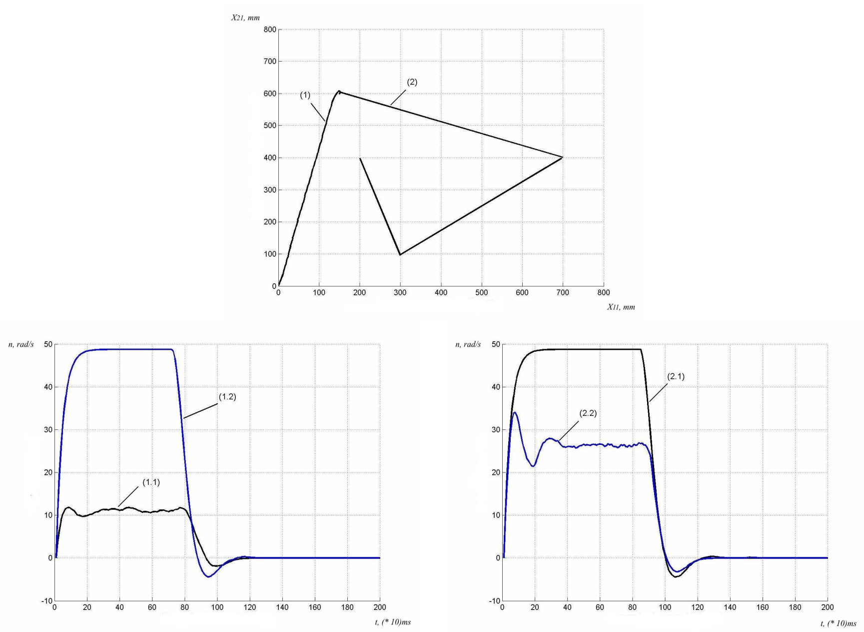

Fig. 3. Modeling results of two-coordinate positioning system

The modeling showed that acceptable quality of the controlled process could be obtained if the sample time is less or equal to 0,01 s.
The modelling results show the case of positioning, where the velocity correction block carries out coordination of the motions and velocity correction signal is formed on the base of information about referred positioning displacements ΔX_{11N}, ΔX_{21N} and running displacements (X_{11}, X_{21}) values.
Velocity and position diagrams representing the modelling results of two-coordinate positioning system, illustrating functional peculiarity of that system are shown in Fig. 3. In the case of two-coordinate positioning model vector of referred displacement is equal: 1) $\Delta X_{11N} = 125$ *mm*, $\Delta X_{21N} = 600$ *mm*; 2) $\Delta X_{11N} = 700$ *mm*, $\Delta X_{21N} = 400$ *mm;* 3) $\Delta X_{11N} = 300$ *mm*, $\Delta X_{21N} = 100$ *mm*; 4) $\Delta X_{11N} = 200$ *mm*, $\Delta X_{21N} = 400$ *mm.* Velocity diagrams of master and slave drives displays the coordination of movements.

Figure 4 represents modeling results of two-coordinate scanning system. This figure represents velocity diagrams of shuttle, stepping drive and two different scanning trajectories, when step size of stepping drive is equal S_2 = 225 mm, S_1 =100mm.

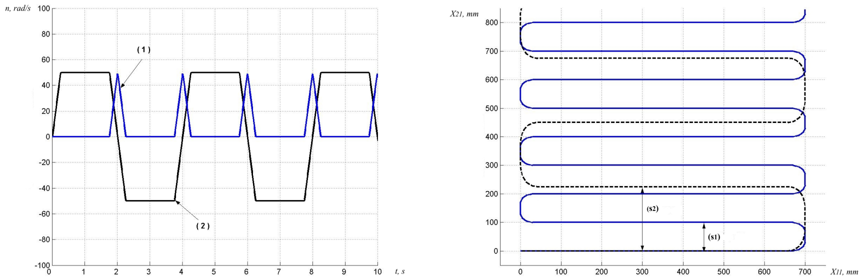

Fig. 4. Modeling results of two-coordinate scanning system

The diagrams show that motions of analysed scanning system are strictly coordinated, i.e. the stepping drive is active only during the reverse mode ($p \notin A$) of shuttle drive, and action time is equal to reverse mode time.
Modelling results show that control principal of two-coordinate drive system, acting both in positioning and scanning mode, guarantees the coordination of both drives. In case of positioning the master drive acts under the conditions of maximal rapidity and slave drive is controlled in such way, which assures the linearity of positioning trajectory. The presented control method enables minimizing power loss and wear of slave drive. In case of two-coordinate scanning control method guarantees stability of velocity of shuttle drive and accuracy of stepping drives; allows minimizing power loss and saving resources of stepping drive.

The main results

This chapter deals with stability analyzes and modeling of two-coordinate drive system.
Quasi-real model was developed for the purposes of functionality analyzes of two-coordinate drive system. The model enables to simulate positioning and scanning processes in real time scale.
The simulation results show the efficiency of proposed control methods for two-coordinate drive system. Simulated control system ensures implementation of specific requirements: guarantee demanded accuracy of drives, maximal rapidity of technological process, optimally use energy and equipment's resources.

3 SYNTHESIS OF MULTIFUNCTIONAL TWO-COORDINATE DRIVE SYSTEM USING AGENTS AND MULTI-AGENT CONTROL SYSTEMS

This chapter analyzes the multi-agent control systems (*MACS)* and their applications. With reference to MACS structuring of control problem of two-coordinate drive system was made. The control problem was divided into complex and partial control problems.
Structural diagram of overall complex control problem is shown in Fig. 5.
For realization of partial control problems separate agents were used. As it was already noted two-coordinate drive system has two tasks. The first task is positioning task, the second – to perform scanning process in defined area. In this case the problem of two-coordinate drive system control is divided into two sub- problems: designing a controller for positioning process control, and designing a controller for operations of scanning process. For solving these two sub-problems the controller-agents will be used. The controller-agent that solves the first sub-problem (positioning process) is called *positioning* and the controller-agent that is used to solve the second sub-problem (scanning process) is called *scanning*. Both controller-agents are combined into a controller agency called *ddvs_control* using a *sequential* coordination mechanism. So the controller-agents get active in a sequential order. When a *positioning* controller-agent gets inactive, this event triggers the activation of the *scanning* controller-agent.
The *position* controller-agent has to operate during the positioning operation of two-coordinate drive system. However the positioning process has its own specifics. The main task of positioning system is assurance of positioning accuracy (quality).

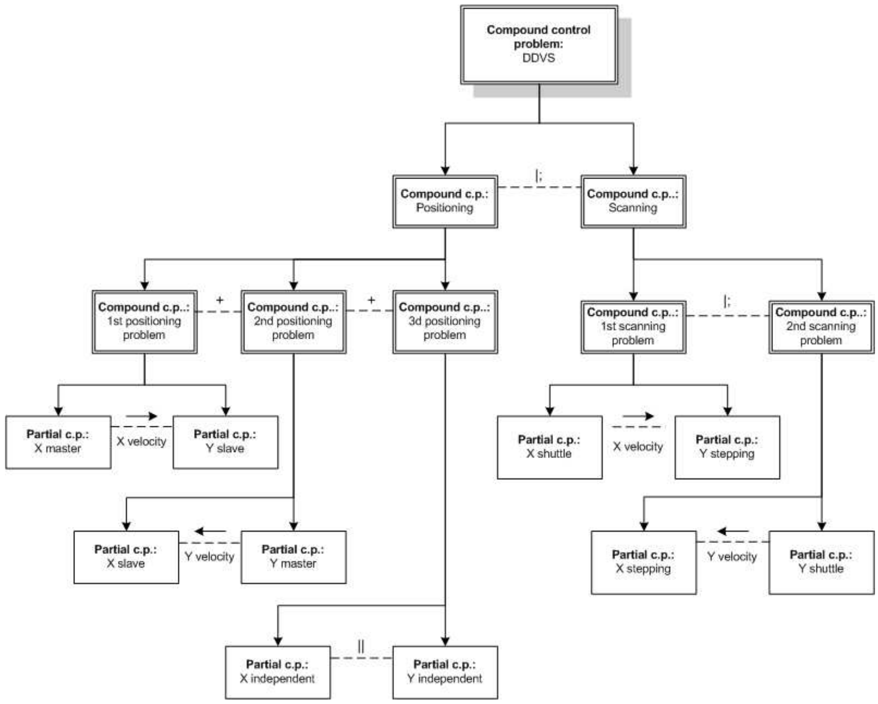

Fig. 5. Structural diagram of control problem of multifunctional two-coordinate drive system

The maximal rapidity of the whole positioning process and minimization of the power loss during the positioning process is to be the second specific problem. Depending on the position sets the three different control modes are available. These situations form three new sub-problems. Designing a controller-agent called *xy_regul* solves the first sub-problem; a controller-agent called *yx_regul* solves the second sub-problem; and the third one – *xy_independ*, solves the third-sub-problem.

The active and inactive states of agents are described by pre-/post-defined conditions. The *xy_regul* agent becomes active, if :

$$p^{xy\_regul} = "-\xi < \left|\Delta X_{11N}\right| - \left|\Delta X_{12N}\right| < \xi", \qquad (5)$$

here ΔX_{11N} – set-point displacement for first drive, ΔX_{11N} – set-point displacement for second drive, ξ – constant, that describes inequality between set-point displacements.

Active agent solves specific partial problem of slave drive control. This is described by expression:

$$U_{GX}(k) = -H_{kr}(z)\left(\frac{\Delta X_{11N}}{\Delta X_{21N}} x_{22}(k) - x_{12}(k)\right) signX_{21N} + H_{P1}(z)\left(\Delta X_{11N} - x_{11}(k)\right), \tag{6}$$

here $H_{kr}(z)$ – regulator transfer function of velocity correction block, $H_{P1}(z)$- proportional position regulator of master drive, $x_{22}(k)$- actual velocity of slave drive, $x_{12}(k)$ – actual velocity of master drive, $x_{11}(k)$- actual position of slave drive.

The productivity of scanning process is defined by shuttle drive velocity, conditioned by technology requirements, and reverse process acceleration. The maximum permissible value of acceleration depends on installation and drive mechanical and electrical overloads possibilities. The stepping drive has to be designed and controlled in such a way, that would not decrease the productivity of the scanning process and it would be able to make a step of appointed size during the reverse time of the shuttle drive. The specific tasks of shuttle and stepping drives in scanning process form another two sub-problems. Designing a controller-agent called *xy_scan* solves the first sub-problem, when the first drive acts as shuttle, the second – as stepping drive; designing a controller-agent called *yx_scan* solves the second sub-problem, when the first drive acts as stepping, the second – as shuttle drive. After solving all partial control problems all agents are combined in overall multi-agent control system.

The main results

In this chapter design tasks of control system were solved. There was proposed and researched the control method of multifunctional two-coordinate drive system, using agents and multi-agent control systems. This method enables solving and flexible coordination of tasks of two-dimensional positioning and scanning.

There were proposed algorithms of agents that solve partial and compound problems in control and coordination of positioning and scanning task in two-dimensional space.

4 EXPERIMENTAL INVESTIGATIONS OF FUNCTIONALITY OF MULTIFUNCTIONAL TWO-COORDINATE DRIVE SYSTEM

This chapter is represented to experimental research of two-coordinate drive system. Functional research of two-coordinate drive system was carried out using two industrial servo drives. It consisted of two frequency converters, servomotors, toothed belt drives and industrial programmable controller.

Figures 6-7 shows experimental results of functional test of positioning mode. In figure 6 diagrams of statuses of agents and position trajectories of master and slave drives are displayed. Figure 7 shows two-coordinate positioning trajectory and velocity diagrams.

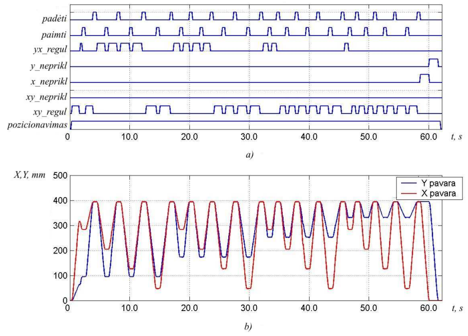

Fig. 6. Diagram of statuses of agents and position trajectories of master, slave drives

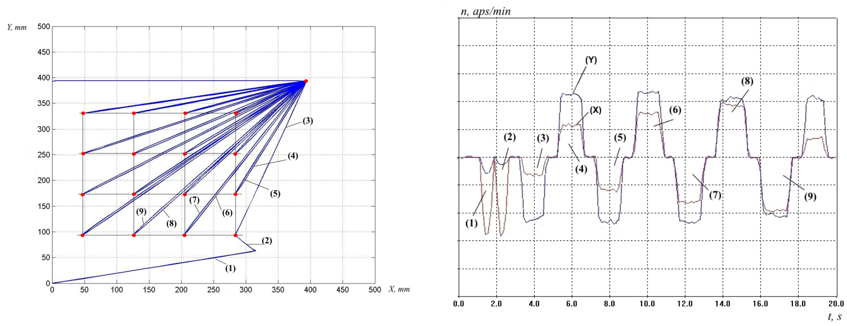

Fig. 7. Two-coordinate positioning trajectory and velocity diagrams

Figures 8-9 shows experimental results of functional test of scanning mode. In figure 8 diagrams of statuses of agents and position trajectories of shuttle and stepping drives are displayed. Figure 9 shows two-coordinate scanning trajectory and velocity diagrams.

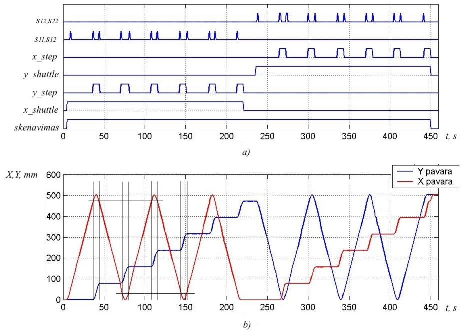

Fig. 8. Diagram of statuses of agents and position trajectories of shuttle, stepping drives

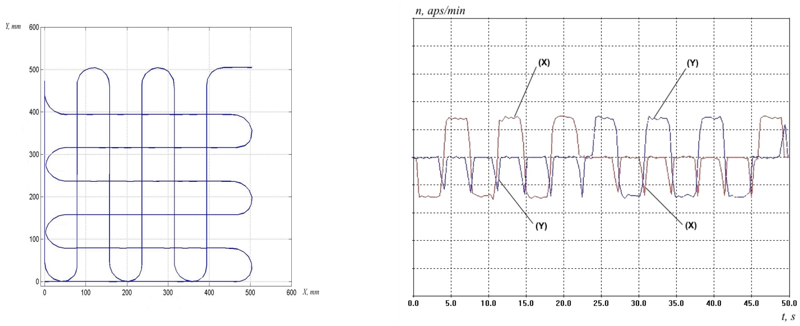

Fig. 9. Two-coordinate scanning trajectory and velocity diagrams

Figures 10-11 shows experimental results of functional test of complex control. In figure 10 diagrams of statuses of agents and position trajectories of drives are displayed. Figure 11 shows positioning, scanning trajectories and velocity diagrams of multifunctional two-coordinate drive system

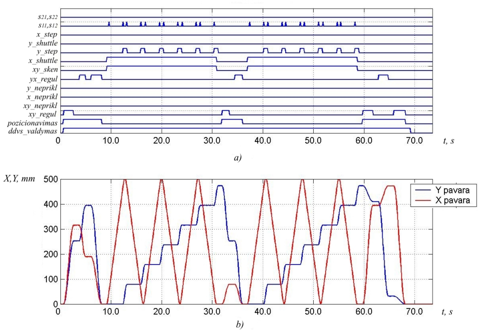

Fig. 10. Diagram of statuses of agents and position trajectories of drives

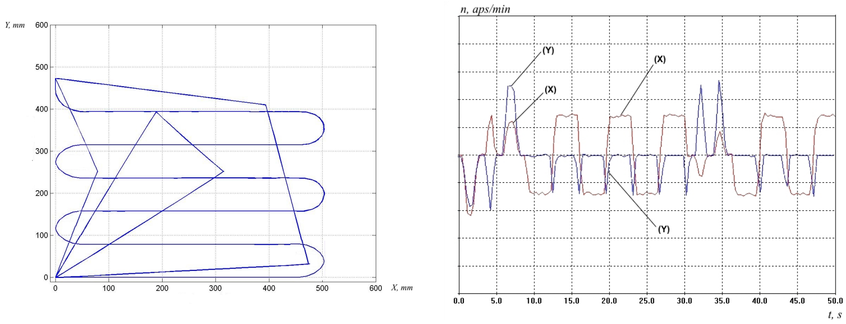

Fig. 11. Positioning and scanning trajectories, velocity diagrams of multifunctional two-coordinate drive system

Experimental researches of functionality of system, consisting of two industrial drives, show efficiency of proposed control method. In positioning mode it allows coordinated control of master and slave drives, assures linearity of positioning trajectory, guarantees power efficiency of system and saves resources of slave drive. In scanning mode proposed control principal allows coordinated control of shuttle and stepping drives, assures stability of velocity of shuttle drive and accuracy of stepping drive, guarantees power efficiency of system and increases durability of stepping drive.

The main results

In this chapter practical realization tasks of two-coordinate drive system control were solved.
The control system of two-coordinate drive system was developed on the base of MACS. Industrial drives with synchronic servomotors and industrial controller were used for experimental research. Every partial control problem was used to solve by appropriate agent.
The experimental results show the functionality of control system solving positioning and scanning tasks in two-dimensional space.
The presented control system enables minimizing power loss and wear of drives, insures linear trajectory in positioning mode, guarantees stability of velocity of shuttle drive and accuracy of stepping drives in scanning mode.

The developed control system of two-coordinate drive system can be used for control of linear, surface gantries, positioning tables, manipulators and in other cases of industrial engineering, where two drives have to be coordinated controlled.

5 QUALITY INVESTIGATIONS OF MULTIFUNCTIONAL TWO-COORDINATE DRIVE SYSTEM

For two-coordinate drive systems designed for handling applications, planar manipulators, positioning of the two-coordinate tables, co-ordination of movements of scanning devices and in many other cases, the most important characteristic data is position repetition accuracy.

It has to be guaranteed that proposed control methods for two-coordinate positioning and scanning system (optimizing of mechanical actions to the mechanical part of the system and power consumption) insure demanded position absolute and repetition accuracy.

Speaking about multifunctional two-coordinate drive system, performing positioning tasks, accuracy of the system, which is controlled using different control methods (sequential, independent, coordinated) have to be analyzed and compared. In control method that insures the linearity of positioning trajectory the bigger displacement performing (master) drive acts under the optimum rapidity conditions and independently form slave drive, meanwhile smaller displacement performing (slave) drive ensures is controlled according the velocity of master drive. Therefore the largest interest lies in behaviour and accuracy of slave drive. In this case the mane object is to investigate the accuracy of slave drive acting under different conditions, determined by different control methods.

Analyzing multifunctional two-coordinate drive system in scanning process, the main purpose was to estimate if accuracy of stepping drive was acceptable enough.

The position repetition accuracy defines the acceptable variation range for numerous approaches to a certain position value. The actual positions approached vary by a statistical expectation from the absolute position deviation (absolute accuracy) relative to a set-point position. For this purpose, the determined position deviation (= actual position value – set-point) of several positioning operations is evaluated statistically.

Repetition accuracy is defined as standard deviation, which is found:

$$\sigma_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\overline{X}_j - X_{ij})^2} \tag{7}$$

In contrast to repetition accuracy, absolute accuracy can be defined as the deviation of arithmetical mean of all position values of a series of measurements from set-point position, i.e.:

$$\Delta X_j = \left| \overline{X}_j - X_j \right| . \qquad (8)$$

The experimental conditions for multifunctional two-coordinate drive system, acting in positioning mode, were: maximum velocity for both drives v_{max} = 0.95 m/s, acceleration a = 4.7 m/s^2. Measurements were carried out at the different set-point values: 1) X_1 = 378 mm, Y_1 = 315 mm; 2) X_2 = 378 mm, Y_2 = 150 mm; 3) X_3 = 378 mm, Y_3 = 30 mm. Number of observation results values n = 90. The increments of resolver of servomotor were used as the observation results values. The relationship between the resolver increments and linear path of toothed belt drive is equal: 1 increment = 0.01575 mm.

Since the research wasn't concentrated on the measuring accuracy but on the comparison of absolute and repetition accuracy of two-coordinate positioning system in different control principals, it was assumed that such measuring technique and means were sufficient for that purpose. Experimental results are displayed in tables 1, 2 and figures 12, 14.

Table 1 shows the comparison of standard deviation for different control methods of multifunctional two-coordinate drive system, acting in positioning mode. From results it can be seen that repetition accuracy of the system using different control methods lies in the same range. From here it can be concluded that using control method, which insures linear trajectory positioning process, two-coordinate drive system is not losing position absolute and repetition accuracy. In this case the load and the accuracy degree of the mechanics standing behind the servomotor is not evaluated, the measurements were made using the measuring system of servomotor (resolver).

Table 1

Comparison of standard deviation of slave drive

Control principal	$\pm\sigma_j, mm$ (68,27%)	$\pm 2\sigma_j, mm$ (95,4%)	$\pm 3\sigma_j, mm$ (99,73%)
Sequential	0.0096	0.0198	0.0288
Independent	0.0108	0.0216	0.0324
Coordinated	0.0113	0.0226	0.0339

Fig. 12 shows the histograms, that represents variation range for numerous approaches of slave drive to defined positions (Y_1 = 150mm, Y_2 = 315mm), when multifunctional two-coordinate drive system is being controlled by method, which insures linear positioning trajectory.

If the repetition accuracy is specified as two times the standard deviation *±2σ*, and drives are coordinated controlled, and probability *P=0.95,* repetition accuracy of slave drive is equal ± 0.0226mm. This means that 95.4% of all positioning operations will lie in the range of $\overline{X}_j \pm 0.0226$mm.

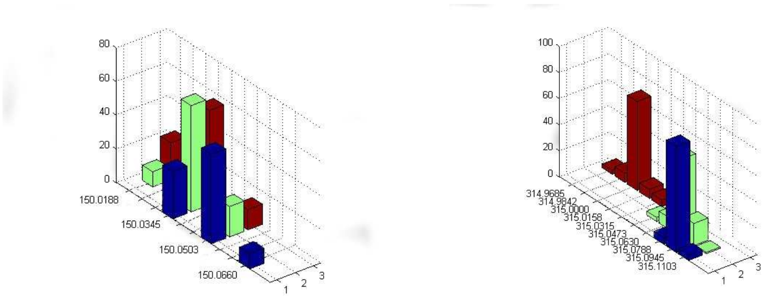

Fig. 12. Histograms representing variation range for numerous approaches of slave drive to defined positions (Y_1 = 150mm, Y_2 = 315mm)

The experimental conditions for multifunctional two-coordinate drive system, acting in scanning mode, were: maximum velocity for shuttle drive v_{max} = 0.38 m/s, maximum velocity for stepper drive v_{max} = 0.24 m/s, maximum acceleration of both drives is equal a = 1.57 m/s^2. Measurements were carried out at the different set-point values. The shuttle drive was moving between to points: $A(126, Y_i)$ mm and $B(315, Y_i)$ mm. The stepper drive moved relatively with defined step size Y_i and number of steps k: 1) Y_1 = 15.75 mm, k = 25; 2) Y_2 = 94.5 mm, k = 4; 3) Y_3 = 189 mm, k = 2. Number of observation results values n = 90.

Table 2 represents the estimation results on absolute and repetition accuracy of scanning mode. Fig. 13 shows the histograms, that represents variation range for numerous approaches of stepping drive to defined steps (Y_1 = 15.75mm, Y_2 = 189mm), when multifunctional two-coordinate drive system is being controlled by method, which coordination of both drives.

Table 2

Standard deviation of stepping drive

Control principal	$\pm\sigma_j, mm$ (68,27%)	$\pm 2\sigma_j, mm$ (95,4%)	$\pm 3\sigma_j, mm$ (99,73%)
Coordinated	0.1224	0.2448	0.3672

In the case of scanning mode the estimation results of different control methods can’t be compared, because of different control techniques. In sequential control principal position feedback signal is used for control of stepping drive. In case of coordinated control principal set-point signal for stepping drive is determined from actual velocity signal of shuttle drive; there is no position feedback signal.

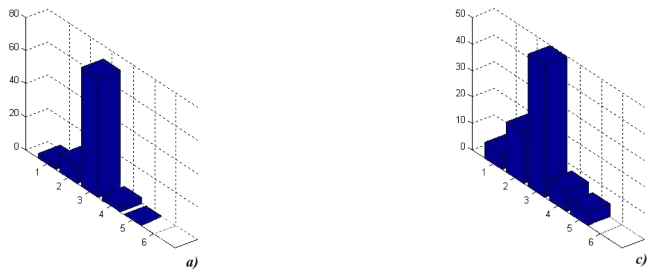

Fig. 13. Histograms representing variation range for numerous approaches of stepping drive to defined steps

If the repetition accuracy is specified as two times the standard deviation $\pm 2\sigma$, and drives are coordinated controlled in scanning mode, and probability $P=0.95$, repetition accuracy of stepping drive is equal ± 0.2448mm. This means that 95.4% of all positioning operations will lie in the range of $\overline{X}_j \pm 0.2448$mm.

The main results

From experimental results and statistical evaluations it could be seen that the repetition and absolute accuracy of two-coordinate drive system do not come worse using control methods that ensure maximal rapidity and optimization of mechanical actions to the mechanical part of the system (the long life of the system increasing) and optimization of power consumption (the power efficiency increasing). Therefore, it can be concluded that multifunctionality of two-coordinate drive system doesn’t influence the positioning accuracy.

CONCLUSIONS

1. Control tasks of multifunctional two-coordinate drive system were formulated. Solutions of these tasks are related to common control objectives, grouped according priorities – guarantee demanded accuracy of devices, ensure maximal productivity of process and minimize expenditures of energy and equipment’s resources.

2. Stability analyzes demonstrated that multifunctional two-coordinate drive system, consisting of two identical velocity systems, described by time constant $T_Ω$=0.0285s and gain $k_Ω$=10, is stabile, if sampling time lies in the range .of 0.01 … 0.001 s.

3. The digital quasi-real time model of multifunctional two-coordinate drive system was created and investigated. Model allowed analyzing functionality of system in scale of real time. Data sampling time of model was adequate to data sampling time of real control system.

4. The model enabled to predict that in positioning mode two-coordinate drive system assures linearity of positioning trajectory, guarantees power efficiency of system and saves resources of slave drive, in scanning mode - guarantees coordinated control of shuttle and stepping drives, assures stability of velocity of shuttle drive and accuracy of stepping drive, saves resources of energy and stepping drive.

5. There was proposed and researched control method of multifunctional two-coordinate drive system, which enables solving and flexible coordinating of tasks of two-dimensional positioning and scanning.

6. It was demonstrated that developed control methods and algorithms enable to coordinate control of master and slave drives, assure linearity of positioning trajectory, guarantee power efficiency of system and save resources of slave drive in positioning mode. In scanning mode proposed control methods allow to control coordinately shuttle and stepping drives, assure stability of velocity of shuttle drive and accuracy of stepping drive, guarantee power efficiency of system and increase durability of stepping drive.

7. It was demonstrated that multi-agent control system is well suited for realization and coordination of control problems (two-dimensional scanning, positioning) of multifunctional two-coordinate drive system.

8. Proposed control methods that realize coordinated control of drives, do not influence the positioning quality of multifunctional two-coordinated drive system. It was estimated that during coordinated positioning mode slave drive was functioning with repetition accuracy of ±0,02mm.

PUBLICATIONS RELATED TO DISSERTATION

Publications in Lithuanian Editions Approved by the Department of Science and Studies

1. Blažiūnas G., Geleževičius V. Accuracy Investigations of Multifunctional Two-coordinate Drive System // Elektronika ir elektrotechnika. 2004, Nr.2 (51) - ISSN 1392 –1215 // Kaunas: Technologija, 2004. P.8-14.
2. Blažiūnas G., Geleževičius V. A multi-agent based control of two-coordinate drive system // Elektronika ir elektrotechnika. 2003, Nr.3 (45) - ISSN 1392 –1215 // Kaunas: Technologija, 2003. P.31-35.
3. Geleževičius V. A., Blažiūnas G. Real-Time Modelling of Harmonious Computer Controlled Two-coordinate Positioning Systems // Elektronika ir elektrotechnika. 2002, Nr.2 (37) - ISSN 1392 –1215 // Kaunas: Technologija, 2002. P. 84-88.

Publications in the Proceedings of International Conferences

1. Blažiūnas G., Geleževičius V. Real-time model of two-coordinate scanning system // Proceedings of CCA2003 (International Conference on Control Applications), - ISSN 1085-1992. Istanbul, Turkey, 2003. P.1153-1157.
2. Geleževičius V. A., Blažiūnas G. Computer controlled harmonious two-coordinate positioning system // Proceedings CD of PEMC'2002 (10th international "Power electronics and motion control" conference) - ISBN 953 – 184 – 046 - 6 // Dubrovnik, Croatia, 2002.

Other publications

1. Geleževičius V. A., Blažiūnas G. Dvikoordinačių vykdymo sistemų daugiafunkcinių valdymo algoritmų modeliavimas. - ISBN 9986-13-965-1 // Automatika ir valdymo technologijos -2001. Konferencijos pranešimų medžiaga // Kaunas: Technologija, 2001. P. 128-131.
2. Geleževičius V. A., Blažiūnas G. Synthesis of Digital Control Algorithms of The Multipurpose Two-Co-ordinate Servo Systems // Elektronika ir elektrotechnika - 2001. Konferencijos pranešimų medžiaga. - ISSN 1392 – 9631 // Kaunas: Technologija, 2001. P. 65-68.
3. Bernotas E., Blažiūnas G. Elektromechaninės vykdymo sistemos Profibus magistralėje // Automatika ir valdymo technologijos -2004. Konferencijos pranešimų medžiaga. - ISBN 9955-09-644-6 // Kaunas: Technologija, 2004. P. 133-137.

ACKNOWLEDGEMENT

I am very grateful to my supervisor prof. habil. dr. V. Geleževičius for his supervision and guidance during all the work. Also I would like to thank Festo UAB for contribution in equipment for experimental research and its personal for great support and understanding. I appreciate my wife for her patience and help as well.

Information about the author of the dissertation

1994-1998: bachelor's degree studies at Kaunas University of Technology, Faculty of Electrical Engineering and Control Systems; acquired degree of qualification – Bachelor of electrical engineering science.

1998-2000: master's degree studies at Kaunas University of Technology, Faculty of Electrical Engineering and Control Systems; acquired degree of qualification – Master of electrical engineering science.

2000-2004: PhD studies in electronics and electrical engineering at Kaunas University of Technology, Faculty of Electrical Engineering and Control Systems.

Nuo 2004: timework-lecturer at department of control technology.

REZIUMĖ

Esminis šiuolaikinių technologinių sistemų bruožas – jų daugiamatiškumas. Tokiose sistemose reikia suderintai valdyti technologinio proceso eigą lemiančius judesius, garantuojant pageidaujamą proceso našumą bei tausojant energetinius ir įrenginių išteklius. Daugiakoordinatės ir dvikoordinatės vykdymo sistemos dažniausiai naudojamos objektų pozicionavimo daugiamatėje ar dvimatėje erdvėje bei kontūrinio valdymo sistemose. Daugiamačio ar dvimačio pozicionavimo atvejais galinis vykdymo įtaisas ar objektas transportuojamas iš pradinio į nustatytą galinį erdvės tašką, neteikiant didesnės svarbos judesio trajektorijai. Tipinis pozicionavimo pavyzdys – *paimti ir padėti* (angl. pick & place) operacijos. Kontūrinio valdymo sistemose galiniam vykdymo įtaisui numatyta judėti pagal nustatytą trajektoriją. Keletas tipinių kontūrinio valdymo pavyzdžių – virinimas, pjovimas arba dažymas. Visos šios paminėtos vykdymo sistemos priklauso plačiai paplitusių daugiakoordinačių vykdymo sistemų grupei – dvikoordinatėms vykdymo sistemoms. Pastarosios taip pat naudojamos metalo pjovimo staklių koordinatinio ir kontūrinio programinio valdymo sistemose, kur apdorojamos detalės ar valdomi darbo įrankių judesiai, koordinatiniams stalams nustatytose padėtyse pozicionuoti, arba suteikiant darbo įrankiams specifinį judesį, kai apdorojami ar zonduojami plokštieji paviršiai ir kitais atvejais, kai reikia suderintai valdyti dviejų ar keleto vykdymo įtaisų judesius.

Šiuolaikinių mechaninių, elektroninių ir informacinių technologijų integracija vykdymo sistemoms suteikia galimybę, naudojant tam tikrą unifikuotą įrangą (variklius, energijos keitiklius ir reguliatorius, proceso būsenos koordinačių jutiklius) ir skaitmenines informacijos apdorojimo priemones (valdiklius, kompiuterius), nekeičiant sistemos konfigūracijos, lanksčiai diegti įvairias technologines funkcijas realizuojančius valdymo algoritmus, t.y. plėsti tokių vykdymo sistemų funkcines galimybes.

Bendrąja prasme, tiek didinant vykdymo sistemų funkciškumą, tiek tausojant energetinius išteklius ar pačių įrenginių resursą, sprendžiamas globalus materialinių išteklių tausojimo ir racionalaus jų naudojimo uždavinys, įgyjantis vis didesnę svarbą nuolat intensyvėjančios gamybos ir vartojimo sąlygomis. Tačiau techninėms sistemoms keliamų reikalavimų kontekste resursų tausojimas nėra aukščiausio prioriteto uždavinys.

Visais minėtais atvejais – objektų orientavimo, vykdymo įtaisų judamos dalies padėties nustatymo ir keitimo uždavinių tikslas – užtikrinti pozicionavimo kokybę yra aukščiausio prioriteto uždavinys. Svarbiausias pozicionavimo sistemų kokybės rodiklis – statinis tikslumas, apibrėžiamas įėjimo ir išėjimo signalų nesutapimu – galutiniu pozicijos nuokrypiu.

Antrasis pagal svarbą daugiakoordinatėms ir dvikoordinatėms vykdymo sistemoms keliamas uždavinys – optimali greitaveika, kuri ypač aktuali, kai intensyvios gamybos atveju siekiama didžiausio įrenginio našumo ir tenka trumpinti technologinių operacijų ciklus.

Įrenginio optimalią greitaveiką lemia maksimalūs leistini pozicionavimo greičiai ir pagreičiai, kuriuos tenka apriboti priklausomai nuo konkrečių vykdymo sistemų techninių galimybių. Veikiant sistemą maksimaliais momentais ir jėgomis, įrenginiai sparčiau dėvisi. Tokiu būdu išryškėja įrenginių dėvėjimosi problema.

Kuriant ir diegiant daugiafunkcinius, energijos, įrenginių ir globalius materialinius išteklius tausojančius dvikoordinačių vykdymo sistemų valdymo algoritmus, būtina garantuoti, kad funkciškumo plėtotė bei diegiami algoritmai nepakenktų jų tikslumui ir nesumažintų bendrosios dvikoordinačių vykdymo sistemų greitaveikos.

Išanalizavus užsienio ir Lietuvos autorių mokslinius darbus, galima teigti, kad:

- vienmačio pozicionavimo atvejis bei jo valdymo principai yra pilnai išnagrinėti;
- tyrinėjant dvikoordinates ar daugiamates vykdymo sistemas orientuojamasi į naujų valdymo principų, leidžiančių užtikrinti maksimalią vykdymo įtaisų greitaveiką bei vykdymo sistemų tikslumą;
- valdymo būdai, leidžiantys tausoti įrenginių ir energijos resursus dvikoordinačio ir daugiamečio pozicionavimo atveju nėra pilnai ištyrinėti;
- dvikoordinatės vykdymo sistemos analizuojamos kaip sistemos, atliekančios siauros paskirties uždavinius; nėra pasiūlyta valdymo metodų, įgalinančių padidinti pastarųjų sistemų daugiafunkciškumą.

Nors dvikoordinatės vykdymo sistemos nėra nauja daugiamačių vykdymo sistemų klasė, tačiau neištirti ir nepateikti valdymo metodai, leidžiantys padidinti šių sistemų daugiafunkciškumą, kuris leistų spręsti globalius materialinių išteklių tausojimo ir racionalaus jų naudojimo uždavinius, apjungiančius ir energijos bei įrenginio išteklių tausojimą, neišnagrinėtos techninės tokių sistemų realizavimo galimybės. Atsižvelgiant į tai, kad dvikoordinatės vykdymo sistemos yra plačiai paplitusios, jų valdymo metodų kūrimas ir tyrimas yra svarbus uždavinys.

Darbo tikslas

Sukurti dvikoordinačių vykdymo sistemų lankstaus valdymo metodus ir algoritmus, įgalinančius tausoti energetinius, įrenginio bei globalius materialinius išteklius, atliekant dvikoordinačio pozicionavimo ir nustatytų paviršių skenavimo procesų valdymą optimalaus našumo sąlygomis.

Uždaviniai

- Ištirti dvikoordinačio pozicionavimo, skenavimo uždavinius ir juos realizuojančias valdymo sistemas pagal joms keliamus reikalavimus – garantuoti reikiamą vykdymo sistemos tikslumą, maksimalų našumą bei globalių materialinių ir įrenginio, energijos išteklių tausojimą.
- Sudaryti dvikoordinatės vykdymo sistemos struktūras, įgalinančias ta pačia technine įranga realizuoti funkciniu požiūriu skirtingus valdymo uždavinius dvimatėje erdvėje.
- Sudaryti dvikoordinatės vykdymo sistemos modelį, leidžiantį analizuoti daugiafunkcinės dvikoordinatės vykdymo sistemos funkcionalumą ir stabilumo sąlygas.
- Ištirti dvikoordinačių vykdymo įtaisų valdymo būdus, realizuojančius skirtingus dvimačius (pozicionavimo, skenavimo) uždavinius bei jų lankstų koordinavimą.

Darbo naujumas. Šiame darbe autorius gina:

- Daugiafunkcinių dvikoordinačių vykdymo sistemų principus, leidžiančius realizuoti funkciniu požiūriu skirtingus valdymo uždavinius (dvikoordinatį pozicionavimą ir skenavimą), siejamus bendrais valdymo tikslais – garantuoti pageidaujamą proceso tikslumą, maksimalią greitaveiką bei tausoti globalius įrenginio išteklius.
- Valdymo būdus ir priemones, įgalinančius sukurti daugiafunkcinę, daugiatikslę dvikoordinačio pozicionavimo – skenavimo sistemą, garantuojančią pageidaujamą pozicionavimo ir skenavimo procesų kokybę, maksimalios bendrojo proceso greitaveikos sąlygomis ir tausojančią energetinius, įrenginio bei globalius materialinius išteklius.
- Multi-agentinę valdymo sistemą, įgalinančią spręsti dvikoordinačių vykdymo sistemų daugiafunkcinius (pozicionavimo ir skenavimo) uždavinius bei šių uždavinių koordinavimo ir valdymo problemas.

Praktinė darbo vertė

Pagrindinis daugiafunkcinių dvikoordinačių vykdymo sistemų praktiškumo požymis yra galimybė realizuoti funkciniu požiūriu skirtingus pozicionavimo ir skenavimo valdymo uždavinius, nekeičiant techninės įrangos. Pasiūlytais valdymo būdais užtikrinamas pastarųjų uždavinių sprendimas ir tenkinami specifiniai dvikoordinatės vykdymo sistemos reikalavimai: garantuojama pageidaujama proceso kokybė, bendra proceso greitaveika, prailginamas įrenginių ilgaamžiškumas bei mažinamos energijos sąnaudos ir tausojami globaliniai materialiniai ištekliai. Šio darbo rezultatai padės spręsti tiek technines, tiek ekonomines bei ekologines daugiafunkcinių dvikoordinačių vykdymo sistemų kūrimo ir eksploatacijos problemas.

Išvados

1. Suformuluoti daugiafunkcinių dvikoordinačių pozicionavimo – skenavimo sistemų valdymo uždaviniai, kurie siejami bendrų valdymo tikslų, suskirstytų pagal prioritetus – užtikrinti vykdymo įtaisų tikslumą, garantuoti maksimalų našumą bei tausoti energijos ir įrenginio išteklius. Šiems funkciniu požiūriu skirtingiems uždaviniams realizuoti apibrėžta ir pagrįsta daugiafunkcinės dvikoordinatės vykdymo sistemos struktūra, apjungianti bendrą techninės įrangos bazę.

2. Atlikta dvikoordinatės pozicionavimo sistemos stabilumo analizė diskretizavimo periodo atžvilgiu parodė, kad naudojant skaitmeninius valdymo algoritmus dvikoordinatė pozicionavimo sistema, sudaryta iš dviejų identiškų greičio reguliavimo sistemų, apibrėžtų laiko pastoviąja T_{Ω}=0.0285s ir perdavimo koeficientu k_{Ω}=10, yra stabili, kai diskretizavimo periodas apibrėžtas $T \in [0.01...0.001]$ s ribose.

3. Sudarytas ir ištirtas skaitmeninis kvazi-realaus laiko modelis, leidžiantis analizuoti dvikoordinatės vykdymo sistemos funkcionalumą realaus laiko mastelyje bei maksimaliai priartinantis modeliuojamos sistemos funkcionavimą prie realių sistemos veikimo sąlygų.

4. Naudojant sukurtą modelį, nustatyta, kad dvikoordinatei vykdymo sistemai veikiant pozicionavimo režime, suderintai valdomi du vykdymo įtaisus, užtikrinama maksimali greitaveika ir tiesinė pozicionavimo trajektorija. Dvikoordinatei vykdymo sistemai veikiant skenavimo režime, užtikrinamas slankiojamojo ir pastūmos judesio įtaisų suderintas valdymas, minimizuojamos energijos ir pastūmos įrenginio resursų sąnaudas.

5. Pasiūlyta ir išanalizuota daugiafunkcinės dvikoordinatės vykdymo sistemos multi-agentinė valdymo sistema, įgalinanti spręsti ir lanksčiai koordinuoti funkciniu požiūriu skirtingus valdymo uždavinius. Remiantis multi-agentinių valdymo sistemų sudarymo metodika, suformuluoti, struktūrizuoti bei išspręsti daugiafunkcinių dvikoordinačių vykdymo sistemų pozicionavimo, skenavimo uždaviniai.

6. Sukurtos daugiafunkcinės dvikoordinatės valdymo sistemos funkcionalumo tyrimai įrodo, kad pasiūlyti metodai ir algoritmai: pozicionavimo režime įgalina suderintai valdyti vedantįjį ir vedamąjį vykdymo įtaisus, užtikrinant tiesinę pozicionavimo trajektoriją bei garantuojant sistemos energetinį ir vedamojo vykdymo įtaiso išteklių eikvojimo efektyvumą; skenavimo režime - slankiojamojo ir pastūmos judesio įtaisus, mažinant bendras energijos bei pastūmos vykdymo įtaiso išteklių sąnaudas.

7. Nustatyta, kad multi-agentinė valdymo sistema yra tinkanti spręsti ir koordinuoti daugiafunkcinės dvikoordinatės vykdymo sistemos pozicionavimo, skenavimo bei kompleksinio (pozicionavimo-skenavimo) uždavinius.

8. Nustatyta, kad naudojami valdymo metodai, realizuojantys suderintą dviejų vykdymo įtaisų valdymą bei garantuojantys sistemos energetinį ir vykdymo įtaisų išteklių eikvojimo efektyvumą, neįtakoja dvikoordinatės vykdymo sistemos pozicionavimo kokybės. Ištirta, kad vykdymo įtaisai suderintame režime funkcionuoja su ±0,02mm pasikartojamu tikslumu.

Trumpa informacija apie disertacijos autorių

1994-1998: bakalauro studijos Kauno technologijos universitete, elektrotechnikos ir automatikos fakultete. Įgytas kvalifikacinis elektros inžinerijos mokslo bakalauro laipsnis.
1998-2000: magistro studijos Kauno technologijos universitete, elektrotechnikos ir automatikos fakultete. Įgytas kvalifikacinis elektros inžinerijos mokslo magistro laipsnis.
2000-2004: elektronikos ir elektros inžinerijos krypties doktorantūros studijos, Kauno technologijos universitete, elektrotechnikos ir automatikos fakultete.
Nuo 2004: dėstytojas-valandininkas valdymo technologijų katedroje

UDK 62-83-52 + 681.51] (043)

SL 344. 2005-03-18. 1 leidyb. apsk. 1. Tiražas 70 egz. Užsakymas 143.
Išleido leidykla „Technologija“, K. Donelaičio g. 73, 44029, Kaunas
Spausdino leidyklos „Technologija“ spaustuvė, Studentų g. 54, 51424, Kaunas