THE MULTI - MOTOR DRIVE MODEL FOR TEACHING IN THE MOTION AND PROCESS CONTROL ENGINEERING

Daniela PERDUKOVÁ – Pavol FEDOR – Jaroslav TIMKO
Faculty of Electrotechnics and Informatics, Technical University of Kosice, Letna 9, 042 00 Kosice, Slovak Republic, ++421 55 602 2256, daniela.perdukova@tuke.sk, pavol.fedor@tuke.sk , jaroslav.timko@tuke.sk

SUMMARY

Technological line control with drives coupled by each other through moving web material is qualitative different from individual drive control because there is necessary to take into consideration their mutual couplings. Due to economical and practical reasons it is difficult to teach students in real working conditions and computer systems do not grant sufficient physical image of these systems. For these reasons the physical model for continuous material processing (web of paper, celluloid, tin, ...) has been built. Control system equipped with transputer module, which enables both education in the field of parallel process and education of programming equipment of this system, has been designed. The description of physical model and control system, some results of experimental measurements and possibilities of its utilisation in education are introduced in this paper.

Keywords: *continuous line, physical line model, control system, transputer, parallel system*

1. INTRODUCTION

Motion and process control engineering is placed between areas of drives control and technical cybernetics. Attention is focussed on the design, implementation and practical realisation of controll systems of industrial plants.

One of the typical examples of complex plants is represented by a multi-motor drive of a continuous technological line. The serious study of subjects dealing with drives working in technological processes, their digital controll system and other equipment meets many principal difficulties which can be described shortly by next factors:

- identification and research of properties and parameters of those processes in real operation require a great expense and technological process in industry cannot be often interrupted or disturbed for purpose of teaching and experimentation (question of economy, productivity, safety,...)
- control system design for those technological processes can be done only in the parts and their realisation as a whole can bring problems due to internal couplings between process subsystems
- in many cases the parallel processes are considered and from this point of view there are no suitable analytical means for simulation of their mutual co-operation, they can be tested only in the way of practical realisation
- only computer simulation of those processes does not provide sufficient physical image about internal mutual couplings between individual processes for students
- only computer simulation of time dependencies in parallel processes can lead to very complicated and unrealisable models

In order to obtain the most practical experience in laboratory conditions it is suitable to make up the physical models of technological processes, which are very close to real processes with their properties. Typical representative of those processes is continuous processing of technological material by continuous line (web of paper, celluloid, tin, ...) and control of this system by distributed (often parallel) control systems.

Moreover the realisation of the model enables to utilise them in practical teaching of other topics as identification, control without feedback, logical control, design and verification of complex algorithms for the control of drives.

2. CONCEPT OF THE CONTINUOUS LINE PHYSICAL MODEL

Main requirements, which were given on physical model of the continuous line are as follows:

- to enable sensing all basic electrical and physical variables
- to enable adjusting basic line parameters (mainly elastic properties of material)
- economical and safe real working

For this purpose the mechanical arrangement of continuous line has been designed and realised according to fig.1. The physical model of continuous line consists of three basic parts:

- input part – consists of an unwrapping machine
- middle part – is created by various portions with loop or direct mechanical coupling
- output part – consists of a winding machine

The physical model consist of 5 motors, which are joined each other by the celluloid or paper web, which creates the mechanical coupling between them. Control voltages for width – pulse converter in range of ± 10V are input variables of physical model

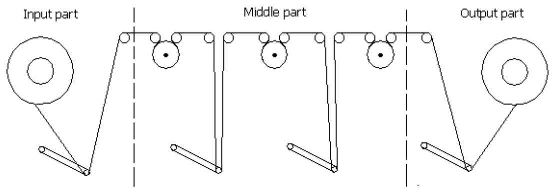

Fig. 1 The structure of the physical model of continuous line

Speeds and tensions of individual drives from position sensors are output variables of the physical model. Tensions in single parts of the line are scanned by position of potentiometers on hanging rollers. Elastic material properties are simulated by mechanical changing spring, which causes the elongation of the web of celluloid.

3. CONCEPT OF THE CONTINUOUS LINE CONTROL SYSTEM

Following requirements were imposed on the control system of the technological process:

- sufficient performance, which enables centralised and decentralised process control
- the connection with attendance adapt to user requirements (for student´s educational process)
- the system should be open, i.e. there is a possibility to interconnect it with other computers or control systems

System which fulfills these requirements is shown in fig.2.

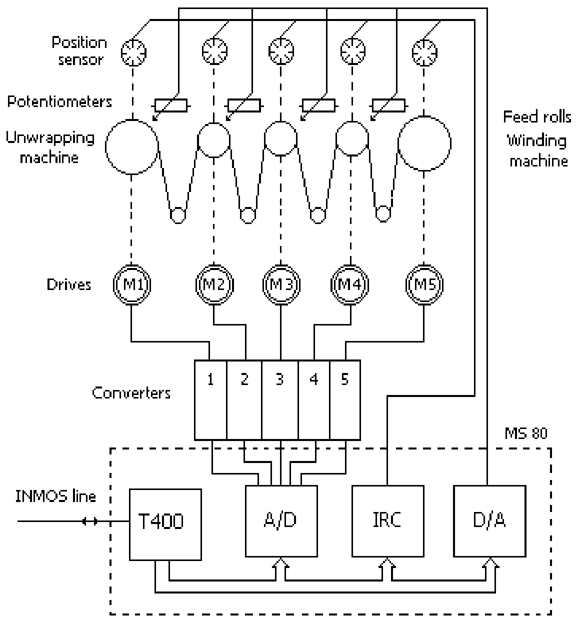

Fig. 2 Structural scheme of the physical model

Control system consists of following units :

- Input/output node –secures the connection between the main part of the control system and technological process by serial link or directly through local bus of some transputer ; this node usually contains A/D, D/A converters, logical input and output, ...
- Computing node (transputers) - which are interconnected with each other by serial link, presents the main part of the system. There is a possibility to extend this main part of the system (theoretically) by arbitrary number of nodes respecting its structure and so the sufficient performance for application can be assured.
- Evolution node – enables to create the particular application by programming means
- Operator node - presents the interface between the system service and net of computing nodes

The application for transputer node is not programmed. It is only compiled from programming modules, prepared in advance, by defining their parameters and mutual couplings between modules. In control system there are next basic types of programming modules:

- computing module – is placed in the transputer; its content is programmed in form of block schemes through standard blocks
- input – output module – serves for connecting with the technological process
- visualisation module - serves for displaying data in required form. It is always stored in one operator node
- control module – enables to control whole control process (start, stop, break point,...). It is always stored in one operator node.

Block diagram of physical model control system is shown in fig.3.

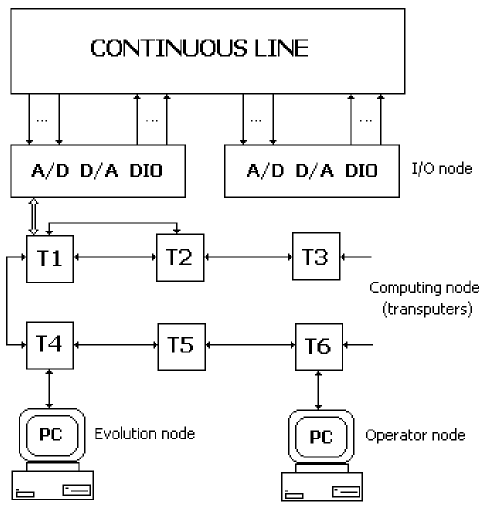

Fig. 3 Block diagram of the control system

The control system designed by this way is very flexible from interconnecting to other systems point of view. The concrete utilisation of this system is much wider. It means that students would be able to programme the transputer perfectly, to design the co-operation between parallel processes, to programme I/O nodes and so on. In addition the creation of a new application takes a very long time and in this case the most of teaching time is devoted to marginal problems (from design and control algorithms verification point of view). For this reason the block-oriented user environment has been designed for this system structure, which enables students to define the function of control system without transputer programming or I/O nodes configuring.

In this system the control algorithms is defined in text form in two steps:

- simulation scheme – it is transcription of block scheme to the block sequence written in simulation language. In this scheme the distribution of computing operations for the transputer net is defined. Inputs and outputs for mutual connection of the modules (transputers) and outputs for the operator node. The simulation scheme is built up from blocks defined in the system in advance.
- configuration file – describes the connection of single modules, their storing into transputer net and the connection between PC and other system modules; this file serves for creating configuration table for the net of transputers.

This environment called GAUSS was described in more details in [1]. All parameters of continuous line model are listed in [3] Appendix C.

4. VERIFICATION OF PHYSICAL MODEL AND EXPERIMENTAL RESULTS

The function of multi-motor drive model with transputer system has been verified for control of line speed and tension in the web of material. The control system consisted of

- MESIT (MS 80) system – which is used for realisation of system input/output and contains next equipment:
  - D/A cards
  - A/D cards
  - logic input/output card
  - incremental sensors card
  - card with transputer T400 – which processes data from technological process in advance and secures convenient shape of output signals for converters
- Transputer net with transputer T800 – which is placed in personal computer and serves for processing equations of control algorithms
- PC computer – serves as graphical and displaying station. Simultaneously the personal computer serves as development node for software of both transputers to see fig.4.

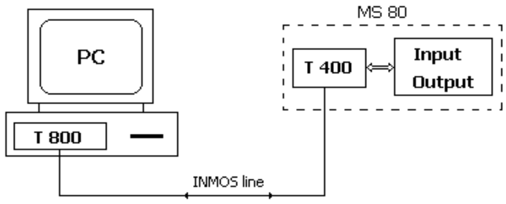

Fig. 4 Control system structure with transputers

Both nodes are connected through fast serial link INMOS and simultaneously the development node enables the interconnection to next transputer nodes by using of further INMOS-links.

The whole control system of continuous line is shown in fig.5.

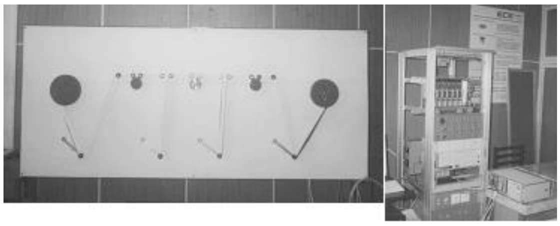

Fig. 5 Continuous line control system

Control algorithm for continuous line has been designed on basis of the II. Lyapunov method for systems with reference model introduced in [1].

The proposed controlled structure supposes the state description of controlled system in the form:

$$\dot{\mathbf{x}} = \mathbf{A_S} \,.\, \mathbf{x} + \mathbf{B_S} \,.\, \mathbf{u} + \mathbf{v_1} \tag{1}$$

where $\mathbf{A_S}$, $\mathbf{B_S}$ are non-linear, time-invariant system matrices, $\mathbf{v_1}$ is vector of additive disturbances and $\mathbf{u}$ is input vector of the system.

The dynamic properties are described by the linear reference model with state description:

$$\dot{\mathbf{x}}_\mathbf{M} = \mathbf{A_M} \,.\, \mathbf{x_M} + \mathbf{B_M} \,.\, \mathbf{w} \tag{2}$$

where $\mathbf{A_M}$, $\mathbf{B_M}$ are constant matrices and $\mathbf{w}$ is vector of required values.

We will reach the aim of the control if controlled structure is able to keep the state deviation equal to zero or at least very close to zero between the reference model (2) and the controlled system (1) :

$$\mathbf{e} = \mathbf{x_M} - \mathbf{x} \tag{3}$$

Because it is not important what caused the disturbance, but important is how to regulate it, we can sum up the influence of parametric and additive disturbances into one generalised disturbance vector **v** :

$$\mathbf{v} = (\mathbf{A_M} - \mathbf{A_S}).\mathbf{x} + \mathbf{B_M}.\mathbf{w} + \mathbf{v_1} \tag{4}$$

When we mark the compensating vector as

$$\mathbf{k} = -\mathbf{B_S}.\mathbf{u} \tag{5}$$

then by combining (1) and (2) through (3) we obtain the system, whose state variables are the elements of vector **e.** That system is described by state equation:

$$\dot{\mathbf{e}} = \mathbf{A_M}.\mathbf{e} - \mathbf{B_S}.\mathbf{u} + \mathbf{v} = \mathbf{A_M}.\mathbf{e} + \mathbf{k} + \mathbf{v} \tag{6}$$

The controlled structure must adjust the vector **k** in such a way that the length of vector **e** would be the smallest or very close to zero.

One of the possible ways for the design of this controlled structure is the second Lyapunov method. It consists in the design of an appropriate positive definite Lyapunov´s function for system (6) and in the choice of vector **k** in such way that the derivative of this function would be negative definite. From conditions of Lyapunov´s theorem about stability there follows the result $\lim_{t \to \infty} \mathbf{e} = \mathbf{0}$

Let us choose Lyapunov´s function in the form:

$$V = \mathbf{e_T}.\mathbf{P}.\mathbf{e} + \sum_{i=1}^{n} \frac{1}{b_i}.(k_i + b_i.d_i.z_i)^2 \tag{7}$$

where

$$z_i = \sum_{k=1}^{n} p_{ki}.e_k \tag{8}$$

and **P** is a symmetric positive definite matrix, which corresponds to Lyapunov´s equation

$$\mathbf{A_M^T}.\mathbf{P} + \mathbf{P}.\mathbf{A_M} = -\mathbf{Q} \tag{9}$$

If we chose the vector **k** in the form

$$\dot{k}_i = -b_i.z_i - b_i.d_i.\dot{z}_i \tag{10}$$

then the derivative of Lyapunov´s function (7) will be

$$\dot{\mathbf{V}} = -\mathbf{e^T}.\mathbf{Q}.\mathbf{e} + 2.\sum_{i=1}^{n}(z_i.v_i - b_i.d_i.z_i^2) \tag{11}$$

Conditions of the II. Lyapunov´s theorem will be fulfilled only in the case when conditions (12), (13) are valid.

$$z_i^2 \geq \frac{v_i.z_i}{b_i.d_i}, \quad i = 1, 2, ..., n \tag{12}$$

$$b_i > 0, \; d_i > 0, \quad i = 1, 2, ..., n \tag{13}$$

More details about this method are presented in [1]. The block scheme of presented controlled structure is shown in fig.6, where the possible modifications of controlled structure are represented by the dashed line:

- It is possible to link vector **k** (or at least its some components) with opposite sign to the reference model without any changes of system (6) behaviour
- We can also prescribe the reference model for open controll system and then this system can be controlled by controller **R**, which can be designed by standard methods for linear systems very simply.
- Because we cannot very often change the parameters of the controlled system directly, this system is controlled through input vector **u**, the influence of the vector **k** to single state variables can be transformationed to appropriate components of the vector **u** as far as the form of matrices $\mathbf{B_S}$ allows it.

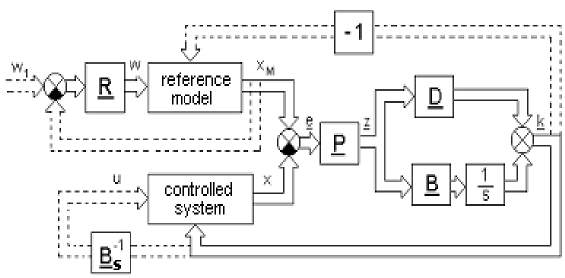

Fig. 6: The block scheme for studying controlled structure

The block scheme of the middle part of the considered continuous line whose physical model consists from two DC motors coupled with each other through the web of material is shown in fig. 7

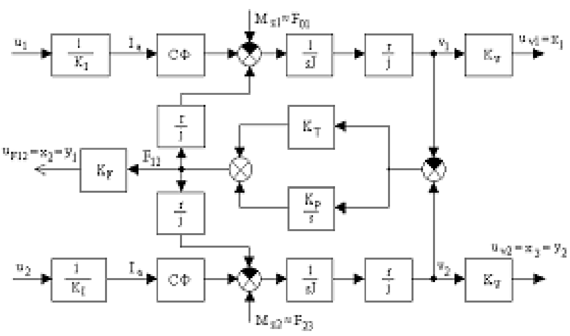

Fig. 7: Two motors coupled with elastic coupling

System state description is in the form (concrete parameters are according [3])

$$\mathbf{A_S} = \begin{bmatrix} 0 & \frac{r^2K_v}{j^2K_FJ} & 0 \\ -\frac{K_FK_P}{K_v} & -2\frac{K_Tr^2}{Jj^2} & \frac{K_FK_P}{K_v} \\ 0 & -\frac{r^2K_v}{j^2K_FJ} & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1.05 & 0 \\ -5.3 & -0.44 & 5.3 \\ 0 & -1.05 & 0 \end{bmatrix} \quad (14)$$

$$\mathbf{B_S} = \begin{bmatrix} \frac{K_vrc\phi}{JjK_i} & 0 \\ -\frac{K_FK_Trc\phi}{JjK_i} & \frac{K_FK_Trc\phi}{JjK_i} \\ 0 & \frac{K_vrc\phi}{JjK_i} \end{bmatrix} = \begin{bmatrix} 0.3 & 0 \\ -0.063 & 0.063 \\ 0 & 0.3 \end{bmatrix} \quad (15)$$

We can see that this system with two inputs and two outputs contains a "quick" tension subsystem and a "slow" speed subsystem. In order to secure autonomy of the control let us choose a reference model created from two autonomous subsystems in the form

$$\mathbf{A_M} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -2 & 0 \\ 0 & 0 & -1 \end{bmatrix} \qquad \mathbf{B_M} = \begin{bmatrix} 1 & 0 \\ 0 & 2 \\ 0 & 0 \end{bmatrix} \quad (16)$$

and controller parameters as follows

$$\mathbf{P} = \begin{bmatrix} 25 & 0 & 0 \\ 0 & 1.25 & 0 \\ 0 & 0 & 25 \end{bmatrix} \quad \mathbf{B} = \begin{bmatrix} 5 & 0 & 0 \\ 0 & 50 & 0 \\ 0 & 0 & 5 \end{bmatrix} \quad \mathbf{D} = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 100 & 0 \\ 0 & 0 & 10 \end{bmatrix} \quad (17)$$

The resulting control structure of the continuous line according II.Lyapunov´s method is shown on fig. 8

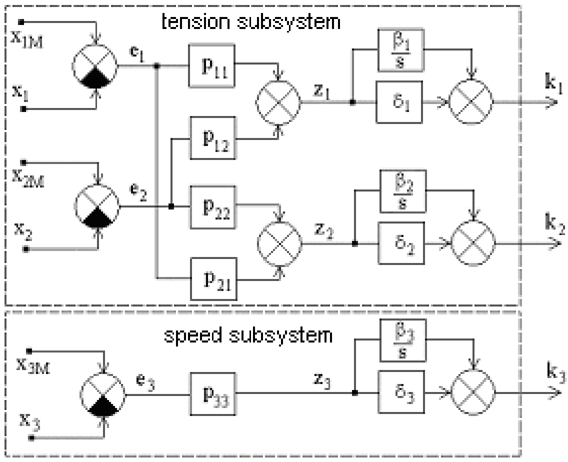

Fig. 8 Continuous line control structure

Next figures present achieved results. Fig.9 shows tension setting between two line machines when line is standing. We can see, that tension in the web of material can be set autonomously with almost aperiodic response.

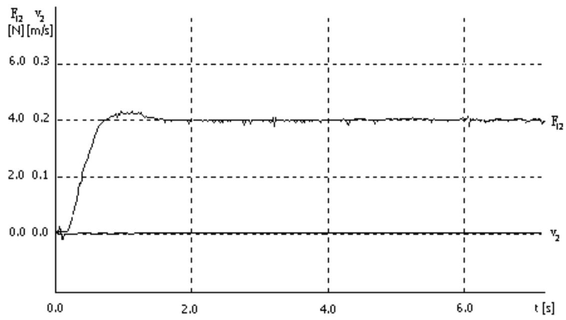

Fig. 9 Autonomy of the tension subsystem

The basic operation states of continuous line, i.e. tension setting F_{12}, continuous line run-up to working point v_2 = 0.5 m/s, the influence of adaptive disturbances to multi-motor line are shown on fig.10. It is obvious that control system was able to control up the fast jumping changes of additive disturbances.

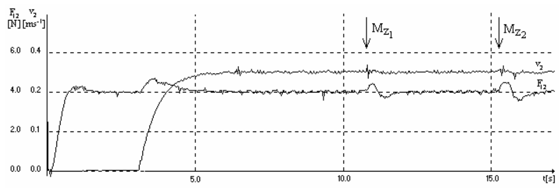

Fig. 10 The basic operation states of continuous line

Additional information about continuous line control by this method is presented for example in [3].

5. CONCLUSION

The description of physical model of continuous line designed for educational process and control algorithm research of complicated technological processes is was described in this paper. Control system working on parallel process base (transputer), which fulfils the condition for effective design of control algorithms, their verification and recovering practical experiences for their utilisation is introduced in this paper, as well. The whole system enables for student to obtain practical knowledge about complicated systems in laboratory conditions. It would be more pretentious in industrial practice.

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BIOGRAPHY

Daniela Perdukova: received the Ing. (MSc) degree in Technical Cybernetics from Technical University of Košice in 1984 and CSc (PhD) degree in 1995. Since 1984, she has been teaching at Technical University of Košice, Department Of Electrical Drives and Mechatronics, where she currently works as Assistant Professor. Her reseach interest includes new control structure development for continuous line control, loading of logic programmable automation in control system in industrial practice and technological process visualisation.

Pavol Fedor: received the Ing. (MSc) degree in Technical Cybernetics from Technical University of Košice in 1980 and CSc (PhD) degree in 1986 at the same University. He is currently an Associate Professor of Power Electronics at the Technical University of Košice at the department Of Electrical Drives and Mechatronics. He has much practical experience in installing of control systems in industry. In theoretical area his current research activities are focused on the development of control structures by means of Lyapunov´s second method for electrical drives and multi-input multi-output systems.

Jaroslav Timko was born in 1938 in Olšinky. He graduated in electrotechnics in Faculty of Electrotechnics of ČVUT Praha. He received his CSc. (PhD) degree at University of Žilina and full Professor in 1988 at Technical University of Košice. His research activities include the Modern Control Strategies for Industrial Automation.