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The Position Control Algorithms for 2-Coordinate Electrical Drive Systems

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ABSTRACT

This paper analyses some position control algorithms for 2-coordinate electrical drive systems. We have developed computer simulation models with different types of motors and conducted detailed studies using computer simulation and experimental research. The results can be used to design and fine-tune these electric drive systems with position control.

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1. Introduction

Two-coordinate electric drive systems are widely used in many industrial applications.

Generally, motions in these systems are formed by the respective trajectories along both coordinate axes. Control algorithms affect the performance, productivity and energy consumption [2], [3], [4].

Time shortening of the transient regimes at positioning is essential for mass production of parts, because it increases the respective machine effectiveness.

Mathematical modeling and computer simulation provide very good opportunities to explore different control algorithms aiming at optimizing of motion trajectories [2], [3], [5]. With respect to modernization of a class of machine toolssome two-coordinate electric drives have been analyzed, allowing the choice of the appropri-

ate once meeting the required performance. Models of such drives have been developed used for studying of different position control algorithms for the respective dynamic and static regimes at different operation modes.

2. Features of the Drive System

The simplified block diagram of the system under consideration is represented in Figure 1, where the notations are as follows: CP – control panel; CD – control device; PC1 and C2 – position controllers; SC1 and SC2 – speed controllers; CC1 and CC2 – current controllers; C1 and !2 – power convertors; M1 and M2 – DC motors; SS1 and SS2 – speed sensors; DM1 and DM2 – driven mechanisms; CF1 and CF2 – current feedback blocks; SF1 and SF2 – speed feedback blocks; PF1 and PF2 – position feedback blocks; V_{pr1} *and* V_{pr2} *– position reference signals;* V_{sr1} *and* V_{sr2} *– speed reference signals;* V_{cr1} *and* V_{cr2} *– current reference signals;* V_{pf1} *and* V_{pf2} *– position feedback signals;* V_{sf1} *and* V_{sf2} *– speed feedback signals;*V_{cf1} *and* V_{cf2} *– current feed-back signals;* θ_1 *and* θ_2 *– angular positions;* S_1 *and* S_2 *– linear displacements.*

The set of achievements required for the drive system can be formulated as follows:

- Forming the necessary motion trajectories at given position cycles;

- Maximum starting torque to ensure good dynamics;

- Reversible speed and torque control;

- Compensation of the disturbances.

3. Modelling of the Drive System

The vector-matrix model of the DC motor drive under consideration is as follows:

$$\begin{bmatrix} \frac{d\theta_i}{dt} \\ \frac{d\omega_i}{dt} \\ \frac{di_{a_i}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & \frac{K_{t_i}}{J_{\Sigma_i}} \\ 0 & -\frac{K_{e_i}}{L_{a_i}} & -\frac{R_{a_i}}{L_{a_i}} \end{bmatrix} \begin{bmatrix} \theta_i \\ \omega_i \\ i_{a_i} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{K_{c_i}}{L_{a_i}} \end{bmatrix} v_i + \begin{bmatrix} 0 \\ -\frac{1}{J_{\Sigma_i}} \\ 0 \end{bmatrix} \tag{1}$$

where: θ_i *is angular position;* ω_i *– motor speed;*

i_{a_i} *- Armature current;*

K_{e_i} *- Back EMF voltage coefficient;*

K_{t_i} *- Torque coefficient;*

R_{a_i} *- Armature circuit resistance;*

L_{a_i} *- Armature inductance;*

K_{c_i} *- Amplifier gain of the chopper;*

v_i *- Input control signal of the power converter;*

J_{Σ_i} - Total inertia referred to the motor shaft;

i_{l_i} - Armature current which is determined by the respective load torque;

i = 2, 1 – Number of the coordinate axes.

Both subsystems have identical cascade structures with subordinate regulation of currents, speeds and positions. Control loops optimization and tuning of the respective controllers have been done sequentially, starting from the innermost ones [1]. For the used mechanical gear maximum operating speed of the motor for the respective coordinate axis is chosen to be equal to the nominal value:

$$\omega_{\max_i} \le \omega_{\text{nom}\,i}\,. \qquad (2)$$

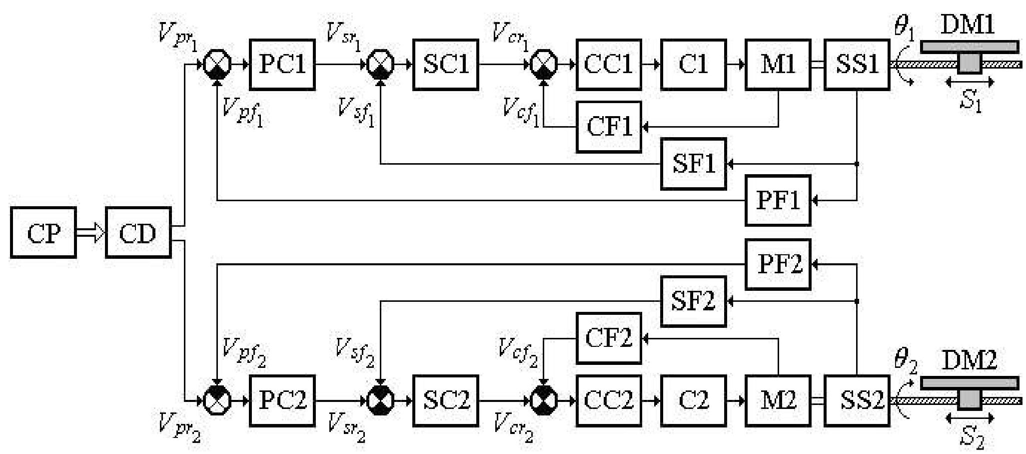

Figure 1. Block diagram of the two-coordinate drive system

The maximum rate of speed change in the respective axis can be determined from the following equation:

$$\varepsilon_{\max i} = M_{\max_i} / J_{\Sigma_i}\ , \qquad (3)$$

where $M_{\max_i}$ is the maximum torque, which the respective motor can develop along this coordinate axis; J_{Σ_i} – total inertia referred to the motor shaft.

For the deceleration motion in this case the following relationship is valid:

$$\Delta\theta_{d\max_i} = \omega^2_{\text{nom}_i} / 2\varepsilon_{d\max_i}\,. \qquad (4)$$

Because subordinate regulation of coordinates is applied, the output voltage of the respective position controller is the assigning speed signal.

$$U_{sr_i} = K_{pc_i}\left(V_{pr_i} - V_{pf_i}\right) = K_{pc_i} K_{pf_i}\left(\theta_{r_i} - \theta_i\right) = K_{sf_i}\omega_{r_i}\,. \qquad (5)$$

Equation (4) for $\Delta\theta_{d\max_i}$ and *ω_{nom_i} and Énomi takes the following form:*

$$K_{pc_i} K_{pf_i} \Delta\theta_{d\max_i} = K_{sf_i} \omega_{\text{nom}_i} . \quad (6)$$

After substituting (4) to (6) and solving with respect to the position controller coefficient, the equation becomes:

$$K_{pc_i} = \frac{K_{sf_i} \omega_{\text{nom}_i}}{K_{pf_i} \left(\omega^2_{\text{nom}_i} / 2\varepsilon_{d\max_i} \right)} = \frac{2K_{sf_i} \varepsilon_{d\max_i}}{K_{pf_i} \omega_{\text{nom}_i}} . \quad (7)$$

For the corresponding mechanical gear the linear speed and linear position can be determined as follows:

$$V_i = \omega_i / K_{gi} ; \; S_i = \theta_i / K_{gi} , \quad (8)$$

where K_{gi} is the respective gear coefficient.

In general, when two-coordinate systems with position control are used, the motion trajectories are formed by the respective displacements of both axes.

Motion trajectories for the studied position control algorithms are presented in Fig. 2, where the symbols used are: (0, 0) – initial position; $A(S_{1f}, S_{2f})$– final position of the specified cycle.

Figure 2a shows a trajectory obtained by successive movement along the coordinate axes. The total time for positioning is as follows:

$$t_p = t_{p1} + t_{p2} , \quad (9)$$

where: *t_{p1} is the motion time along the coordinate axis x ; t_{p2} – the motion time along axis y .*

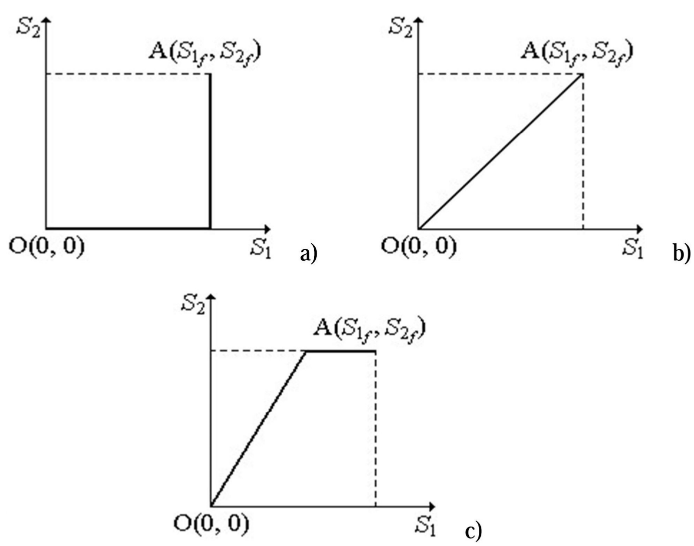

Figure 2. Motion trajectories for two-coordinate position control

a) Consecutive motion along the coordinate axes;
b) Simultaneous motion along the coordinate axes;
c) Combined motion along the coordinate axes.

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Figure 2b represents a trajectory obtained by simultaneous movement along both coordinate axes. In such way of control position time is:

$$t_p = t_{p_1} = t_{p_2} \qquad (10)$$

Figure 2c shows a trajectory obtained at combined motion along the coordinate axes. If both drives work at the same speeds, the total time of positioning is equal to the time necessary for the drive with longer displacement time set.

$$t_p = t_{p_1}. \qquad (11)$$

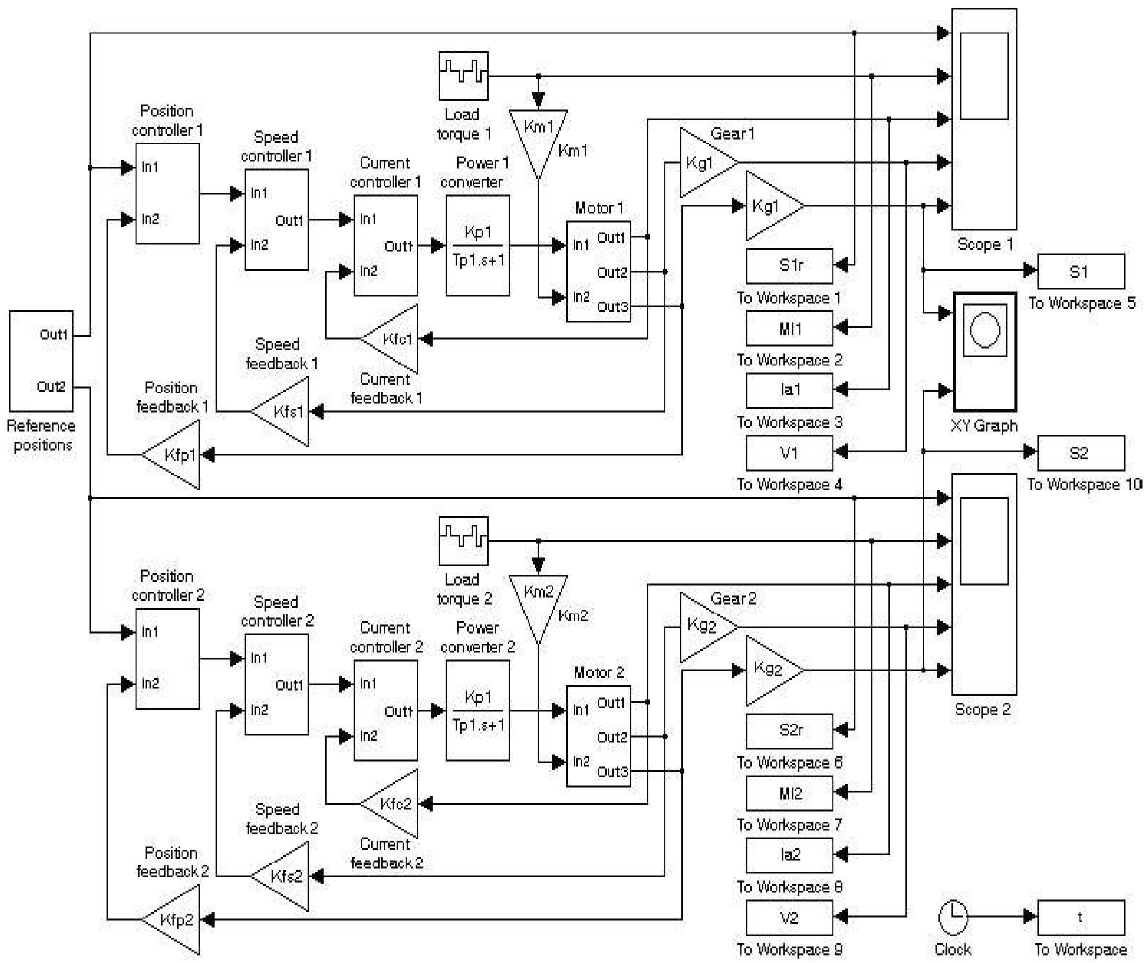


Figure 3. Simulation model of the two-coordinate drive system

In the MATLAB/SIMULINK environment some models of systems for two-coordinate electric drives have been developed with different types of motors. They allow for detailed studies of the respective static and dynamic regimes and analyses of performance. A simplified block diagram of one of the models is presented in Figure 3.

4. Experimental Results and Analysis

The electric drives for both coordinate axes are identical. The DC motors used for modeling and computer simulation have the following parameters:

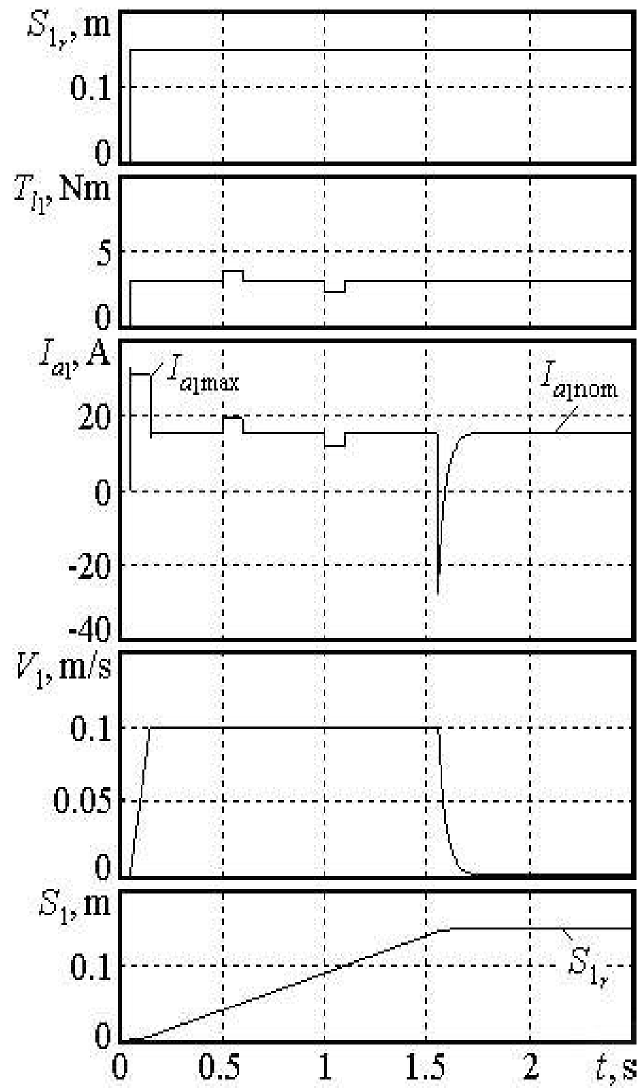


Figure 4. Time-diagrams for a set position cycle along one axis

$V_{\text{nom}_i} = 30$ V ; $I_{a\text{nom}_i} = 15.7$ A ; $\omega_{\text{nom}_i} = 115.19$ rad/s .

Figure 4 shows the time-diagrams obtained by computer simulation during processing a position cycle along the x coordinate. The set displacement S_{1r}, the load torque T_{l1}, the armature current I_{a1}, the displacement speed V*1 and the linear position* S*1 along this coordinate axis are shown. Armature current is limited to the maximum admissible value $I_{a1\max}$. The respective control loops setting provide compensation of the disturbances and smooth positioning without overshooting. The disturbances applied sequentially on the electric drive are $\Delta T_{l_1} = \pm 0.25 T_{l_1\text{nom}}$*

In Figure 5 the trajectories of movement to the same final position have been shown, obtained through different algorithms of movement on both axes.

Figure 5a represents a consecutive motion along the x *and y coordinates.*

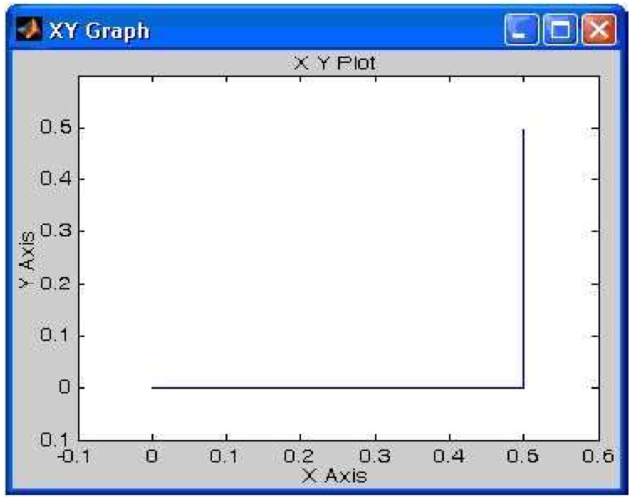
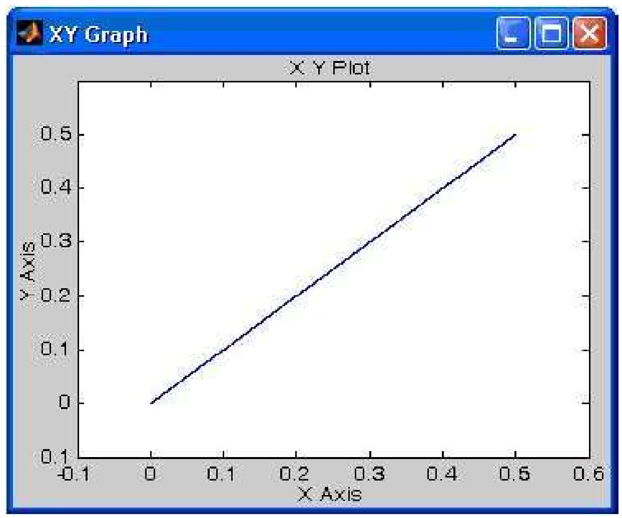


Figure 5b shows the trajectory when simultaneous motion is performed along both coordinate axes.



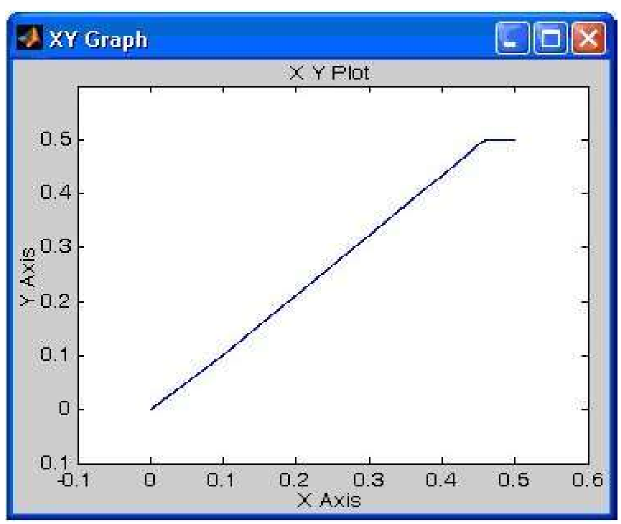


Figure 5. Trajectories for different algorithms of control

Detailed experimental studies have been carried out for different versions of controllers' tuning and operation regimes. Some time-diagrams are presented in Fig. 6, 7 and 8.

Fig. 6 shows a linear speed trajectory, obtained experimentally for displacements of 0.62 m along the coordinate axis x.

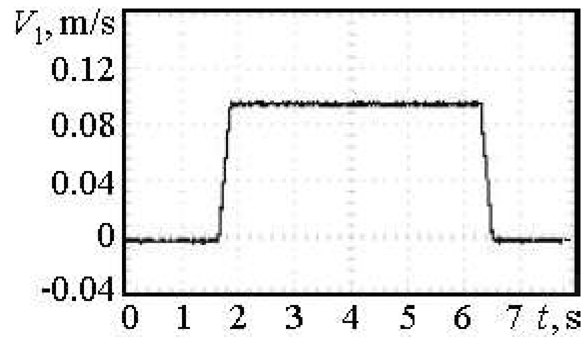


Figure 6. Time-diagram of motion along the x coordinate

A linear speed diagram, obtained for motion along the coordinate axis C is represented in Figure 7.

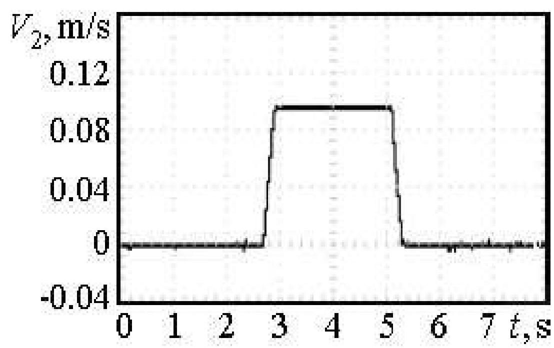


Figure 7. Time-diagram for motion along the coordinate axis *y*

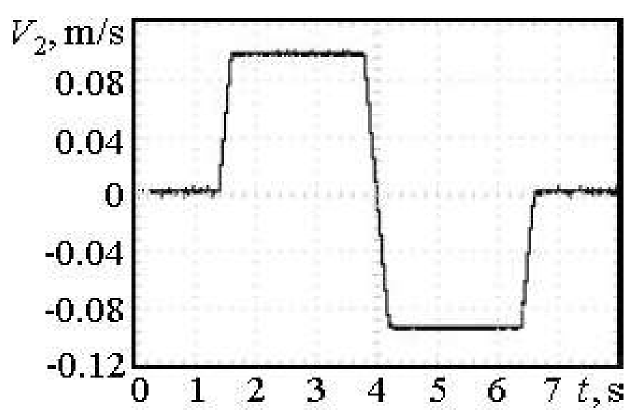


Figure 8. Time-diagram illustrating reverse control along the axis y

The set distance in this case is 0.32 m.

Figure 8 illustrates reverse control. The set distance in both directions is 0.32 m.

The behavior analysis shows that the presented position control algorithms provide for good performance suitable for practical applications.

5. Conclusion

Models for computer simulation of two-coordinate electric drive systems with various algorithms for position control have been developed.

On the basis of computer simulations and experimental studies the presented algorithms for position control have been analyzed.

This research and the results obtained can be used in the design and tuning up of such two-coordinate systems of electric drives.

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