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AN APPROACH TO CONTROL OF MULTI-MOTOR ELECTROMECHANICAL SYSTEMS

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Abstract: An approach to synchronization of the main controlled variables and their ratios in multi-motor drive systems is presented in this paper. According to the offered control algorithm synchronization is always carried out with respect to the lagging electric drive, as determination of the master drive takes place automatically. Application of the described control method to speed synchronization has been studied and discussed. Analysis of the respective dynamic and static regimes shows that the applied control algorithm can provide good synchronization of the controlled variables. The developed computer simulation models and the results obtained can be used in optimization and tuning of such types of multi-motor electromechanical systems.

Key words: *multi-motor driving system, synchronized control, synchronization of speed ratios, accuracy improvement*.

1. INTRODUCTION

Multi-motor driving systems are used in a number of industrial applications. By technological reasons it is often necessary to maintain exact ratios of the main regulated variables such as speed and position.

Generally, several synchronization techniques can be used to meet the requirements of the driven mechanisms, replacing the traditional mechanical coupling. For example, the necessary synchronization can be achieved applying a common reference signal and individual stabilization of the regulated variables for all the electric drives [1]. In order to realize more precise synchronized control, some corrections of the slave electric drive reference signals may be introduced. They should be in accordance with the respective differences between the controlled variables of the master and slave drives [2]. Comparative analysis of several methods of synchronization has been made in [3, 7].

A method and a relevant device for control of dual-motor electric drives aiming at synchronized maintenance of the regulated variables have been proposed in [4]. The performance of some dual- and triple-motor drive systems with control applying this method has been presented in [5] and [6], respectively.

This paper describes and discusses a general approach to control of multi-motor electromechanical systems, which provides the possibility to maintain reference ratios of the respective controlled variables. Some results from the research of such electromechanical systems where the offered method has been applied for synchronized control of speed ratios are also represented. The analysis of the performance in the respective transient and steady-state regimes shows that the control approach presented here provides for a good synchronization at different working conditions.

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2. FEATURES OF THE DRIVE SYTEM

A simplified block diagram of the multi-motor systems under consideration is shown in Fig.1, where the following notations are used: PC – personal computer; LB – logical control block; ED1, ED2, …, ED*n* – electric drives; S1, S2, …, S*n* – sensors for the controlled variables; L1, L2, …, L*n* – loads of the electric drives; $x(t)$ – input common reference signal for the main controlled variable; $x_1(t)$, $x_2(t)$, …, $x_n(t)$ – reference signals for the respective electric drives; $y_1(t)$, $y_2(t)$, …, $y_n(t)$ – feedback signals; $z_1(t)$, $z_2(t)$, …, $z_n(t)$ – disturbances applied to the electric drives; Δy_r – reference dead zone determining the necessary synchronization accuracy.

In such systems the respective feedback signals are being used for both individual stabilization of the controlled variables and realization of synchronized control of the electric drives.

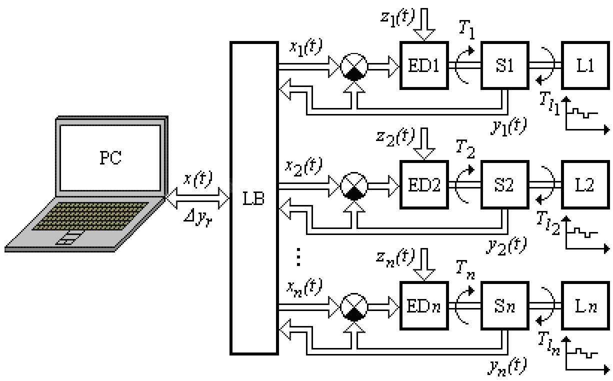


Fig. 1. Block diagram of the systems under consideration.

Speeds or positions are the usual controlled coordinates. The load torque changes ΔT_{l_i} and inertia changes ΔJ_i can be considered as disturbances.

All electric drives of these multi-motor systems can be both identical and diverse. Fig. 2 shows some versions used in the study of such systems. The time-diagrams in Fig. 2a concern an electric drive with brush DC motor while these in Fig. 2b – an electric drive with brushless DC motor. Starting processes and speed stabilization at disturbances are represented. In the transient regimes the respective motor currents are limited to the maximum admissible values, which ensure good dynamics of the multi-motor system. The respective variables are presented in relative units: $\omega_r^* = \omega_r / \omega_{\text{rat}}$ – reference speed; $T_l^* = T_l / T_{l\text{rat}}$ – load torque applied to the motor shaft; $I_a^* = I_a / I_{a\text{rat}}$ – armature current; $i_a^* = i_a / I_{a\text{rat}}$ – current of phase a; $\omega = \omega/\omega_{\text{rat}}$ – motor speed.

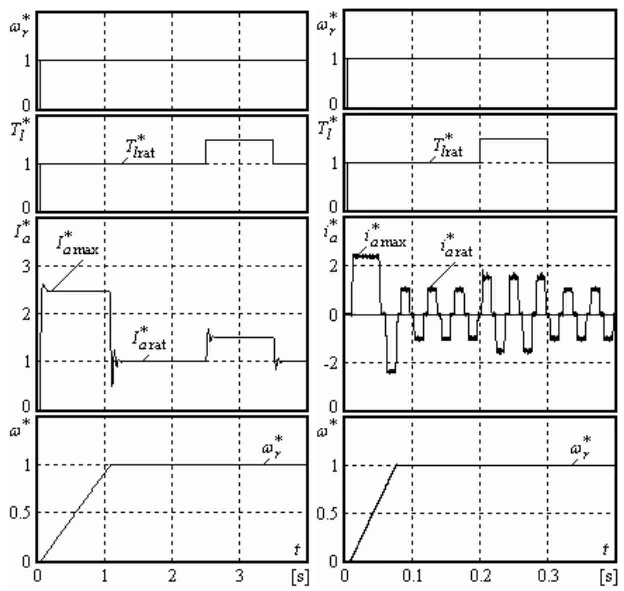


Fig. 2. Time-diagrams for some electric drives.

3. CONTROL ALGORITHM

Figure 3 shows a flowchart of the control algorithm in its general mode. It provides for synchronization of the principal controlled variables in multi-motor electromechanical systems, such as speed or position.

According to the applied control strategy, at the beginning of the starting process, as well as during operation in steady-state regimes, the reference signals for the electric drives are as follows:

$$x_i(t) = K_i x(t), \tag{1}$$

where $K_{i(i=1 \div n)}$ – coefficients determining the ratios of the regulated variables.

To make all feedback signals comparable their values are recalculated:

$$y_i'(t) = y_i(t)/K_i \ . \tag{2}$$

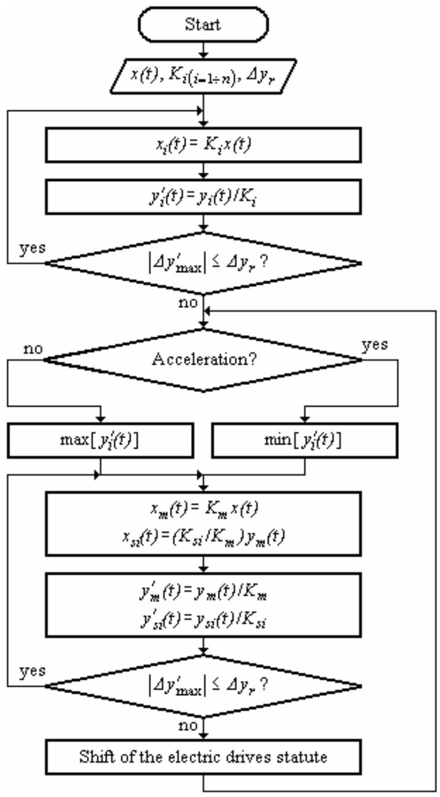


Fig. 3. Flowchart of the control algorithm.

The control continues in accordance with Eq. 1 while the maximum error is within the reference error limits

$$\left|\Delta y_{\max}'\right| \le \Delta y_r \,. \tag{3}$$

The respective feedback signals $y_i'(t)$ are compared to determine the smallest value signal. The drive appearing at the given moment most lagging behind takes the statute of a master, and the rest of $n-1$ electric drives become slaves. The master drive continues to be synchronized by the input reference signal

$$x_m(t) = K_m x(t), \tag{4}$$

while the reference signals for the slaves are determined by the feedback signal of the master electric drive:

$$x_{si}(t) = \left(K_{si} / K_m\right) y_m(t). \tag{5}$$

For comparison, the feedback signals should be recalculated as follows:

$$\left.\begin{aligned} y_m'(t) &= y_m(t)/K_m \\ y_{si}'(t) &= y_{si}(t)/K_{si} \end{aligned}\right\}. \tag{6}$$

When a new lagging occurs, the slowest electric drive automatically becomes the master and the control continues in compliance with Eq. 3 and Eq. 4 respectively**.**

During acceleration the electric drive that has the lowest level of the controlled variable is assumed as a master; at deceleration the master drive will be the one that has the highest controlled variable value. Therefore, the shifting conditions for the electric drives statute are as follows:

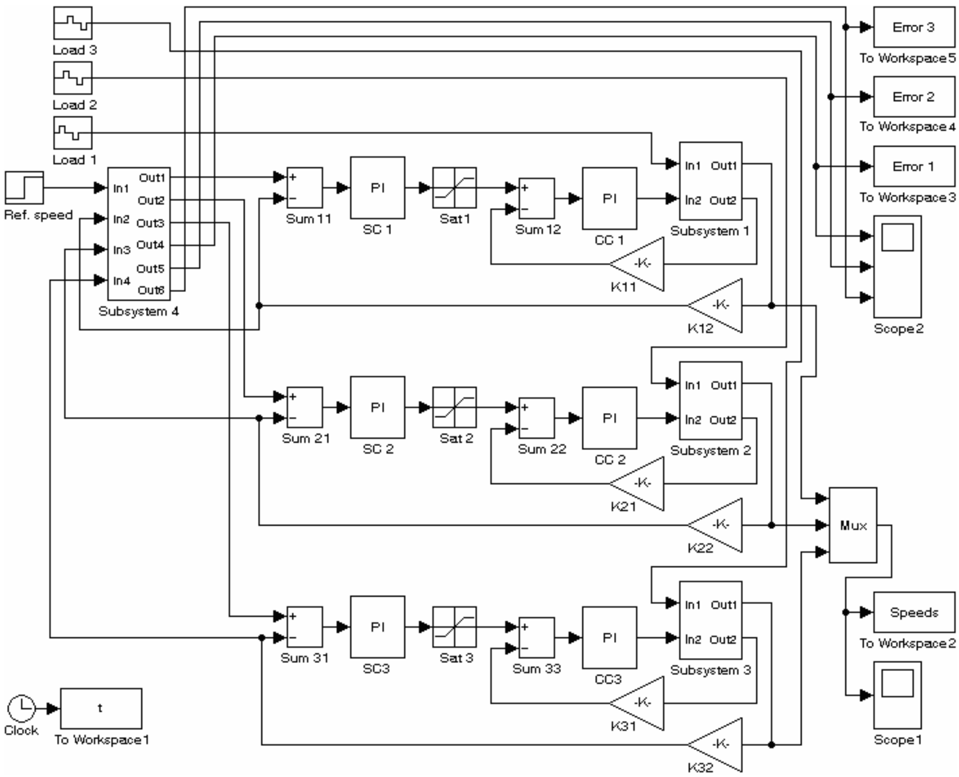


Fig. 4. Simulation model of a multi-motor electromechanical system.

$$\left.\begin{aligned} y_m(t) &= \min\left[y_i'(t)\right] - \text{for acceleration;} \\ y_m(t) &= \max\left[y_i'(t)\right] - \text{for deceleration.} \end{aligned}\right\} \quad (7)$$

This way the required accuracy is achieved in the transient regimes (acceleration and deceleration) with different loads, and in cases of disturbances applied to the respective electric drives.

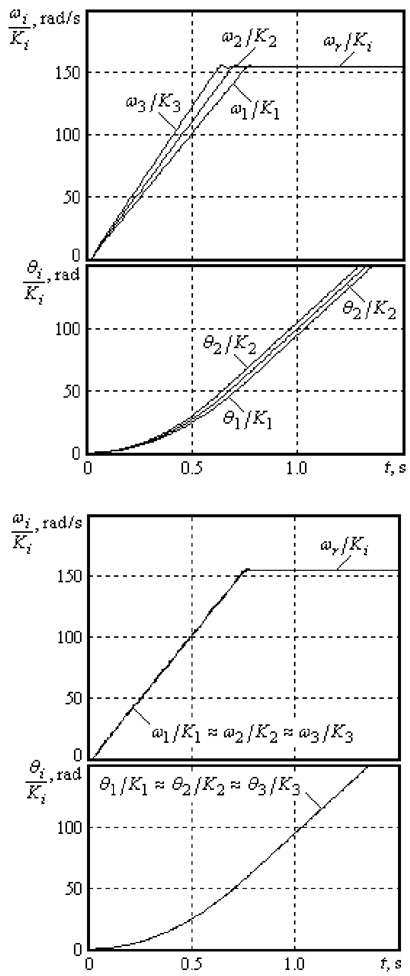
4. PERFORMANCE ANALISYS

To verify the offered control approach functionality a number of computer simulation models have been developed using the MATLAB/SIMULINK software package. Various electric drives have been modeled including both DC and AC motor types. The respective models allow study of a wide range of multi-motor electromechanical systems with different modifications and controlled variables.

A simplified diagram of such a simulation model is shown in Fig. 4 where the notations used are as follows: Subsystem 1, Subsystem 2 Subsystem 3 – electric drives including the respective power converters and DC motors; System 4 – logical control block; SC1 $\div$ SC3 – speed controllers; CC1 $\div$ CC3 – current controllers. The corresponding signals and coefficients for this drive system are as follows: $x \equiv \omega_r$; $\Delta y_r \equiv \Delta\omega_r$; $x_i \equiv K_i\omega_r$; $y_i \equiv \omega_i$; $z_i \equiv \Delta T_{l_i}, \Delta J_i$; $i = 1, 2, 3$.

The system input includes a common reference signal for the main controlled variable ω_r as well as the reference dead zone $\Delta\omega_r$ determining the synchronization accuracy.

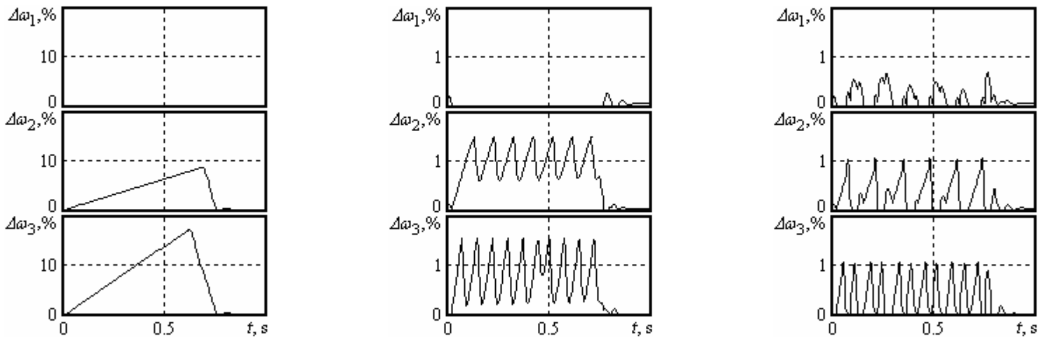
In the electromechanical system under consideration all the electric drives are of the same type and operate as dual-loop cascade control structures.



a

b

Fig. 5. Time-diagrams of the respective speeds and positions.



a b c

Fig. 6. Time-diagrams of the relative speed errors.

Fig. 5 shows some time-diagrams of the respective speeds and positions obtained as simulation results at non-synchronized control (*a*) and synchronized speed control (*b*). In this case the reference condition is as follows: $\omega_r / K_i = 157$ rad/s .

Fig. 6 *a* represents time-diagrams of relative speed errors at non-synchronized control. The errors $\Delta\omega_1$, $\Delta\omega_2$ and $\Delta\omega_3$ are calculated with respect to the slowest electric drive (in this case it is the first one). Because of that, the respective error is $\Delta\omega_1 = 0$. The rather large speed discrepancies are due to the differences between the load inertias J_1, J_2 and J_3.

The respective time-diagrams of the relative speed errors at synchronized control are shown in Fig 6 *b*. The working conditions at which this investigation has been carried out are exactly the same as those of non-synchronized control, but the resulting speed errors $\Delta\omega_i$ have been represented in a different scale. As evident, the errors at synchronized speed control are considerably reduced.

The desired synchronization accuracy can be ensured through setting of the respective reference dead zone $\Delta\omega_r$. For example, in Fig. 6 *c* the reference error of the coordinate ratios is $|\Delta\omega_{max}| \approx 1\%$.

The research has been carried out for electromechanical systems with separately excited DC motors and permanent magnet synchronous motors in brushless DC motor operation mode. The basic parameters of the motors used are as follows:

a) for the brush DC motors: rated power $P_{rat} = 3.4$ kW , rated current $I_{rat} = 17.6$ A , rated speed $\omega_{rat} = 314$ rad/s ;

b) for the brushless DC motors: rated power $P_{rat} = 0.6$ kW , rated current $I_{rat} = 10$ A , rated speed $\omega_{rat} = 157$ rad/s .

5. CONCLUSIONS

A general approach to synchronized control of regulated variable ratios in multi-motor electromechanical systems has been presented. The offered control algorithm is applicable for any types of electric drives, both DC and AC ones.

Appropriate computer simulation models of such systems with control utilizing the described algorithm have been developed.

The possibilities for practical application of this method to synchronized speed control have been studied and discussed. Performance analysis for the respective transient and steady-state regimes allows drawing the following conclusions:

- the control approach presented in this paper ensures a good synchronization at various loads and working conditions;

- except for speed, the presented algorithm for synchronized control is suitable for other basic regulated variables, such as position or acceleration.

The research carried out and the results obtained can be used in optimization and tuning of such types of multi-motor driving systems.

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