Synthesis of system of coordinated control of electric drives with electronic reduction

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Abstract. The paper presents data construction of an electric drive structure with an electronic reduction. The transferred functions of the system for control and disturbing signals are received. The results of mathematical modeling for various operating modes are presented. The sensitivity of the transfer function to specific links is analyzed. Different modes of operation of the coordinated control system are analyzed. The sensitivity of the transfer function to specific links is analyzed. Different modes of operation of the coordinated control system are analyzed.

1. Introduction

Multi-motor, in particular twin-motor, electric drives with coordinated control are widely used in lifting and transport mechanisms [1-3], autonomous objects, electric drives with force reflection and other fields [4]. The issues of coordinated control can be solved in various ways, there are various modifications to the "electric shaft" [8] schemes, electric drives matching the coordinate difference, etc. [6-9]. At the same time, it is possible to construct parametric systems of coordinated rotation [10].

The main advantage of such systems is the simplicity of construction, high reliability, the possibility of increasing the number of coordinated electric drives. In a number of cases, it becomes necessary to introduce an adjustable reduction ratio for one or more matched electric drives. In this case, the principle of consistency should be preserved: the change in the speed of rotation of one electric drive must be reflected in the second, taking into account the established reduction factor. The system in this case works as a variator, but without mechanical contact of the leading and driven axes.

2. Object of study and methods

As the executive engines in the study, two-speed asynchronous motors were used, on the basis of which various speed control systems were created. The effectiveness of the use of separate inclusion of two groups of motor windings is substantiated. Such scheme allows simple, including parametric, methods to control the speed of the considered induction motor, it makes it possible to increase its energy efficiency and improve the power factor.

3. The study of the structure of the system of coordinated control of electronic drives with electronic reduction

The structural scheme of the electric drive in question is shown in Fig.1. The system is operated by:

- speed reference signal ω_{ref} ;

- reduction preset signal K_{red} ;

- the moment of loading on the first engine M_1 ;

- the moment of loading on the second engine M_2 .

    The output signals are:

- speed of rotation of the first engine ω_1 ;

- speed of rotation of the second engine ω_2 ;

- speed signal of the second engine model $\omega_2^{'}$.

    Link $W_1(p)$ characterizes the electrical part of the electric drive, $W_2(p)$ - the mechanical components of the electric drive, $W_3(p)$ - the link of correction.

    The lower branch of the structural diagram in Fig.1. is an electronic model of electric drives of the first and second axes (assuming that their characteristics are identical).
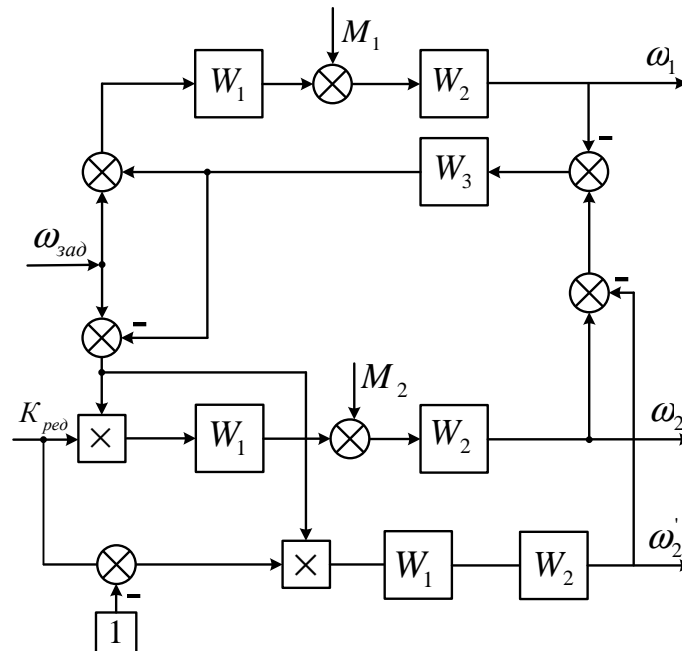

Figure 1. A block diagram of the electric drive.

The system of equations for the transfer functions from the master signal has the form:

$$\begin{cases} \omega_1 = W_1(p) \cdot W_2(p)\left[\omega_{ref} + W_3(p)\Delta\omega\right] \\ \omega_2 = K_{red} \cdot W_1(p) \cdot W_2(p)\left[\omega_{ref} - W_3(p)\Delta\omega\right] \\ \omega_2^{'} = (K_{red}-1)W_1(p) \cdot W_2(p)\left[\omega_{ref} + W_3(p)\Delta\omega\right] \\ \Delta\omega = \omega_2 - \omega_2^{'} - \omega_1 \end{cases}$$

Substitution of equations (1-3) into (4) leads to $\Delta\omega = 0$.

Proceeding from this, the transfer functions of the system from master signal ω_{ref} take the form:

$$\omega_1 = W_1(p) \cdot W_2(p) \cdot \omega_{ref}$$

$$\omega_2 = K_{red} \cdot W_1(p) \cdot W_2(p) \cdot \omega_{ref}$$

$$\omega_2^{'} = (K_{red} - 1)W_1(p) \cdot W_2(p) \cdot \omega_{ref}$$

The system of equations for transfer functions from perturbing effect M_1 has the form:

$$\begin{cases} \omega_1 = \left[M_1 + \Delta\omega \cdot W_3(p) \cdot W_1(p) \right] \cdot W_2(p) \\ \omega_2 = -\Delta\omega \cdot W_3 \cdot K_{red} \cdot W_1(p) \cdot W_2(p) \\ \omega_2^{'} = \Delta\omega \cdot W_3(p) \cdot (K_{red}-1) W_1(p) \cdot W_2(p) \end{cases}$$

Substitution of equations (8-10) into (4) leads to:

$$\omega_1 = W_2(p) \cdot \frac{1 + W_1(p)W_2(p)W_3(p)}{1 + 2W_1(p)W_2(p)W_3(p)} \cdot M_1$$

$$\omega_2 = W_2(p) \cdot \frac{W_1(p)W_2(p)W_3(p)K_{red}}{1 + 2W_1(p)W_2(p)W_3(p)} \cdot M_1$$

$$\omega_2^{'} = -W_2(p) \cdot \frac{W_1(p)W_2(p)W_3(p)(K_{red}-1)}{1 + 2W_1(p)W_2(p)W_3(p)} \cdot M_1$$

Expressions (5-7) can also be used as transfer functions from signal changes K_{red}. It is important that ω_1 does not depend on the change. It should also be noted that there is no link $W_3(p)$ in the transfer functions (5-7). All transient processes ω_1 and ω_2 of control effects (ω_{ref} and K_{red}) differ only in the amplitude scale, which is specified by K_{red}. Based on this link, $W_3(p)$ can be used to correct the system for disturbing effects.

The formation of signals ω_1 and ω_2 also occurs with the help of real electromechanical links. Signal $\omega_2^{'}$ is generated using an electronic model. In the process of working in real parts or models, changes can occur that will lead to a change in the operation of electric drives. To assess this, let us introduce link W_4 in the model chain that will characterize possible changes:

$$W_4 = K_4 \frac{T_{41}p + 1}{T_{42}p + 1}$$

The analysis shows that non-observance of condition $K_4 = 1$ disrupts the operation of the circuit; in particular, this leads to a distortion of the given reduction factor, K_{red}. For the case under consideration, the condition obtained on the basis of expressions (1-4) $\Delta\omega = 0$ will not be observed. The introduction of the link (14) into expressions (1-4) gives the formula:

$$\Delta\omega = \frac{(K_{red}-1)\left[1 - W_4(p)\right]}{1 + W_1(p)W_2(p)W_3(p)\left[K_{red}((1-W_4(p)) + (1+W_4(p))\right]} \cdot \omega_{ref}$$

In this case, $\Delta\omega = 0$ under the following conditions:

$$K_{red} = 1 \text{ or } W_4(p) = 1$$

To assess the ACS of electric drives with respect to the changes in parameters under consideration and the choice of the way to increase the "roughness" of the system, let us use the sensitivity functions [11]. Sensitivity functions $S_{W_i}^{W}$ of transfer function $W(p)$ to link $W_i(p)$ are determined by the expression:

$$S_{W_i}^{W} = \frac{dW(p)}{dW_i(p)} \cdot \frac{W_i(p)}{W(p)}$$

On the basis of formula (17), the following expressions are obtained:

$$S_{W_1}^{W_M} = \frac{-2W_2(p)W_3(p)}{W_1(p)\left[1 + 2W_1(p)W_2(p)W_3(p)\right]}$$

$$S_{W_2}^{W_M} = \frac{1}{W_2^2(p)\left[1 + 2W_1(p)W_2(p)W_3(p)\right]}$$

$$S_{W_3}^{W_M} = \frac{-2W_1(p)W_2(p)}{W_3(p)\left[1 + 2W_1(p)W_2(p)W_3(p)\right]}$$

$$S_{W_1}^{W_{red}} = \frac{1}{W_1^2(p)\left[1 + 2W_1(p)W_2(p)W_3(p)\right]}$$

$$S_{W_2}^{W_{red}} = \frac{1}{W_2^2(p)\left[1 + 2W_1(p)W_2(p)W_3(p)\right]}$$

$$S_{W_3}^{W_{red}} = \frac{-2W_1(p)W_2(p)}{W_3(p)\left[1 + 2W_1(p)W_2(p)W_3(p)\right]}$$

The analysis of expressions (18-23) shows that:

- all have common factor $W(p) = \dfrac{1}{1 + 2W_1(p)W_2(p)W_3(p)}$;

- sensitivity functions for link $W_3(p)$ equal $S_{W_3}^{W_M} = S_{W_3}^{W_{red}}$;

- sensitivity functions for link $W_2(p)$ equal $S_{W_2}^{W_M} = S_{W_2}^{W_{red}}$;

- to reduce the sensitivity functions, one can increase coefficients K_1, K_2, K_3.

In the process of the study, the structure shown in Fig. 1 was modeled. In Fig.2, the graphs of the transient processes of the start ($t = 0$), the change in the reduction coefficient ($t = 1$ c), and the action of the moment M_1 ($t = 3$ c) are given.
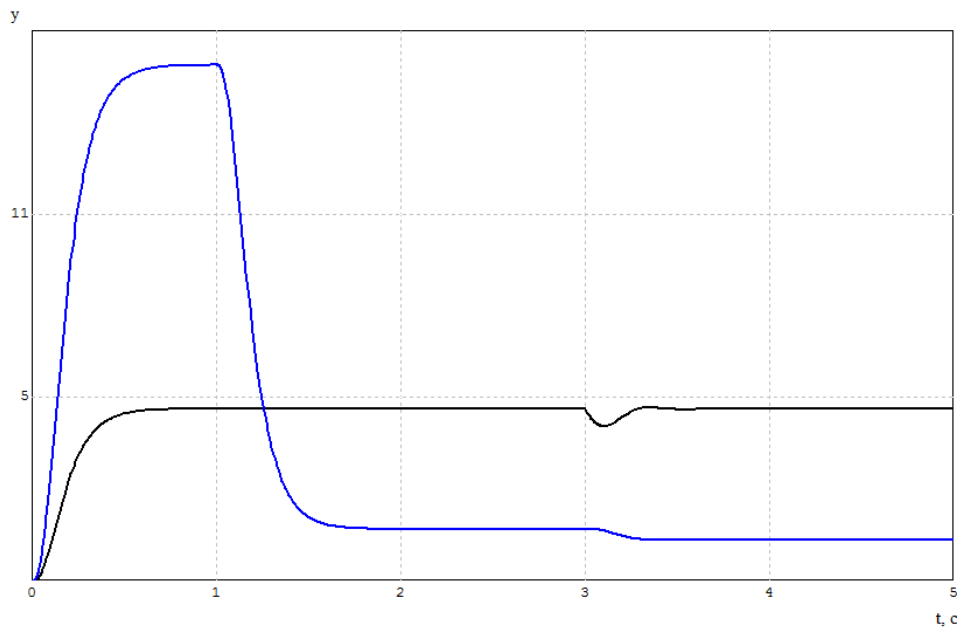

Figure 2. Transient processes of rotation speeds of the first and second engines, ω_1 and ω_2, under the action of the moment of loading M_1.

Analysis of the obtained graphs shows that during the start-up, transient processes ω_1 and ω_2 proceed identically. The change in the reduction ratio on the second electric drive is not reflected in the first. The action of moment M is also reflected by the second electric drive taking into account the reduction coefficient.

In Fig.3. the graphs of the transient processes of the start ($t = 0$), the change in the reduction coefficient ($t = 1$ c), and the action of the moment ($t = 3$ c) are given.

In Fig.4. graphs of transient processes under the action of control and disturbing signals are given, provided that the parameters of the model are not consistent with the real parameters of the electric drives (link $W_4(p)$ is included). Transients correspond to condition $2T_2 = T_1$.
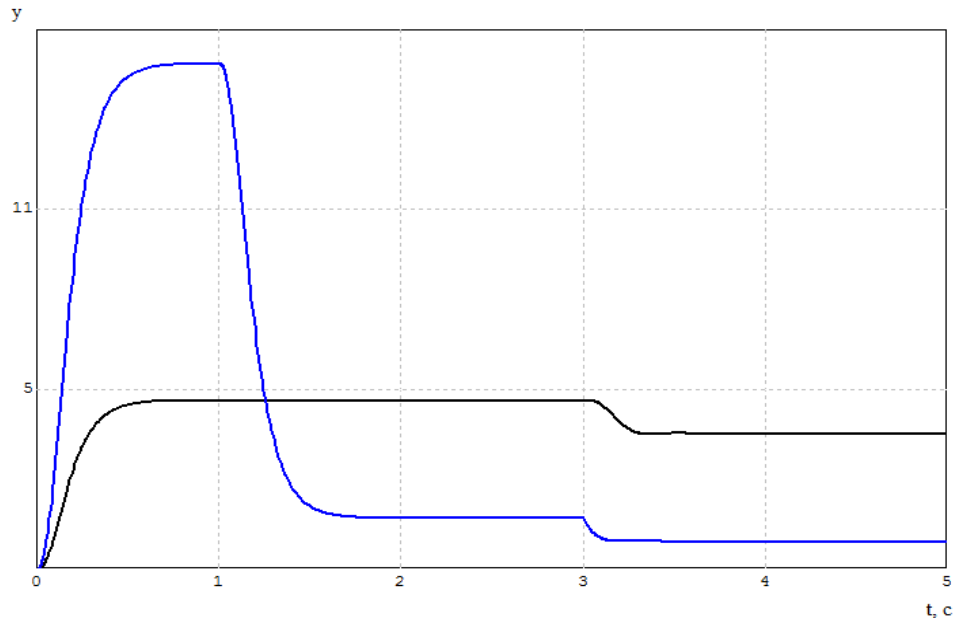

Figure 3. Transient processes of rotation speeds of the first and second engines, ω_1 and ω_2, under the action of the moment of loading M_2.
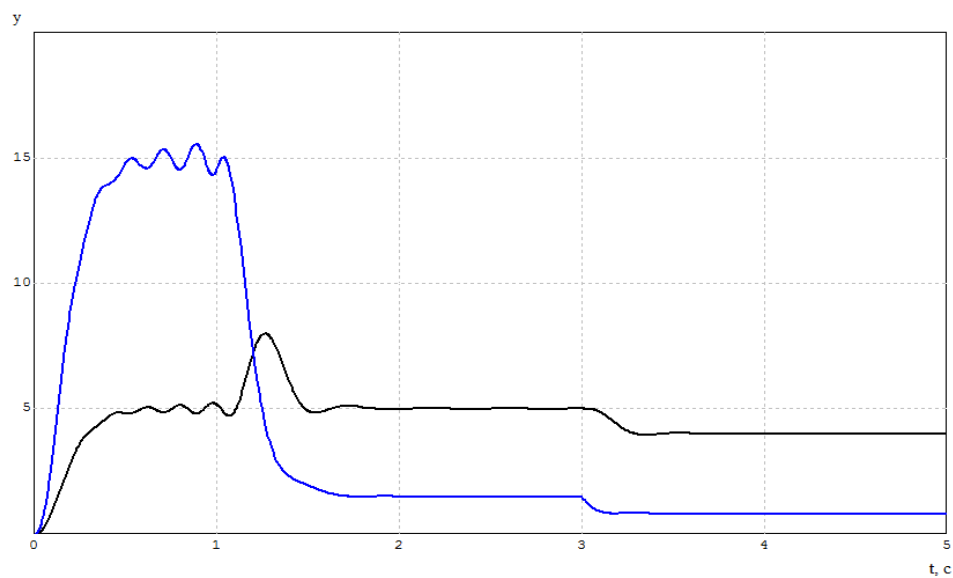

Figure 4. Transient process with mismatch in the model circuit ($2T_2 = T_1$).

4. Conclusion
The conducted researches allow drawing the following conclusions:
- the proposed structure allows one to realize the mode of coordinated rotation;
- the circuit provides a controlled electronic reduction mode of the second electric drive;

- the proposed system of coordinated rotation provides "reflection" of the moment on an unloaded electric drive taking into account the established reduction ratio;
- analysis of sensitivity functions gives the way to reduce it;
- in the event that the parameters of the link of the model differ from the actual values, with a change in the reduction ratio in the transient process of the first electric drive, a dynamic error appears;
- to eliminate the errors that occur when the time constants of the model and the electric drive deviate, an aperiodic link or an intensity detector can be used by setting it at the output of the reduction ratio setting unit;
- in case of difference in transmission factors in the circuits of the model and the electric drive, it is necessary to use the calculator of the real reduction factor and to introduce correction factors into the circuit.

5. Acknowledgments

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