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Dynamics of an Asynchronous Electric Drive with Thyristor Converter at Discrete Control

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ABSTRACT. Questions of optimization of the dynamics of a discretely controlled asynchronous electric drive are studied both for rigid and elastic mechanical shafts. Optimal transfer functions of a discrete regulator of an electric drive system in the *z*-operator form and its parameters are defined. *© 2007 Bull. Georg. Natl. Acad. Sci.*

Key words: *asynchronous electric drive, dynamics, discrete control, optimal regulator, elastic link.*

To obtain a mathematical model of a discretely controlled asynchronous electric drive we first write differential equations for a motor with a rigid mechanical shaft [1, 2]

$$\begin{cases} T_{EM}\dfrac{d\Delta\mu}{dt}+\Delta\mu = 2\cdot\Delta\upsilon_{\phi}; \\ \Delta\mu-\Delta\mu_{ST} = T_M\dfrac{d\Delta\nu}{dt}+\dfrac{1}{\delta_B}\cdot\Delta\nu, \end{cases} \tag{1}$$

where $\Delta\upsilon_{\phi}$, $\Delta\mu, \Delta\mu_{ST}, \Delta\nu$ are respectively relative increments of the voltage of motor phase, torque, static load and rotation velocity of the drive; T_{EM} and T_M are respectively electromagnetic and mechanical constants of the drive time; δ_B is a relative drop of the drive velocity.

For thyristor converter we use the following transfer function [3]:

$$W_T(s) = K_T/(T_T s+1), \tag{2}$$

where K_T is the gain coefficient of the converter; T_T is the time constant of the filter at the converter input.

Using equation (1) and function (2) we can easily define the general transmission function of the drive object with s-operators as follows:

$$W_0(s) = \frac{K_0}{a_0 s^3 + a_1 s^2 + a_2 s + 1}, \tag{3}$$

where $K_0 = 2K_T\cdot\delta_B$; $a_0 = T_T\cdot T_{EM}\cdot\delta_B\cdot T_M$;

$$a_1 = T_T\cdot T_{EM} + T_{EM}T_M\delta_B + T_T\cdot\delta_B\cdot T_M;$$

$$a_2 = T_T + T_{EM} + T_M\cdot\delta_B.$$

Given the parameters $K_T = 25$; $\delta_B = 0.11$; $T_T = 0.01$; $T_{EM} = 0.075$ and $T_M = 11.5$ we decompose (3) into simple rational fractions in the form

$$W_0(s) = \sum_{i=1}^{3}\frac{A_i}{s+\alpha_i},\quad i=\overline{1;3} \tag{4}$$

where $A_1 = 0.6742$; $A_2 = 5.3329$; $A_3 = 4.6587$; $\alpha_1 = -100$; $\alpha_2 = -13.33$ and $\alpha_3 = -0.7805$.

The transfer function corresponding to (4) can be written in the z-converted form as follows:

$$W_0(z) = \sum_{i=1}^{3}\frac{A_1(1-d_i)}{z-d_i}, \tag{5}$$

where $d_i = e^{-\alpha_i T_o}$; T_0 is the discreteness period (T_0 = 0.01, sec.); $d_1 = 0.3676$; $d_2 = 0.8754$; $d_3 = 0.9921$.

Using the numerical values, we can rewrite (5) in the form

$$W_0^*(z) = \frac{7.384 \cdot 10^{-4} z^2 + 0.002261z + 0.0004181}{z^3 - 2.235z^2 + 1.555z - 0.3194}. \quad (6)$$

Performing the frequency analysis of (6) we define the optimal regulator with the transfer function

$$D_0^*(z) = \frac{30z - 26.4}{z}. \quad (7)$$

Using (7) we obtain the transfer function of a closed asynchronous drive system in the case of discrete control

$$W^*(z) = \frac{0.0222z^3 + 0.0483z^2 - 0.0471z - 0.011}{z^4 - 2.212z^3 + 1.6033z^2 - 0.3665z - 0.011}. \quad (8)$$

The roots of the characteristic equation (8) are $z_1 = -0.02676$; $z_2 = 0.8708$; $z_{3,4} = 0.6839 \pm i0.06454$. Since the condition $|z_i| < 1$ is fulfilled for the obtained roots, the considered system of the drive in the case of discrete control is dynamically stable.

Taking into account the elastic properties of mechanical shaft of the drive, we write motion equations for the asynchronous motor in the following form:

$$\begin{cases} \Delta\mu - \Delta\mu_e = T_1 \dfrac{d\Delta\nu_1}{dt} + \dfrac{1}{\delta_B}.\Delta\nu_1; \\ \Delta\mu_e - \Delta\mu_{ST} = T_2 \dfrac{d\Delta\nu_2}{dt}; \\ \Delta\mu_e = \dfrac{1}{T_c}\int(\Delta\nu_1 - \Delta\nu_2)dt + \dfrac{T_d}{T_c}(\Delta\nu_1 - \Delta\nu_2), \end{cases} \quad (9)$$

where T_1 and T_2 are mechanical time constants of inertial masses of the drive; $\Delta\nu_1$ and $\Delta\nu_2$ are respectively the increments of angular velocities of the drive and the mechanism; $\Delta\nu_e$ is an elastic moment increment of the mechanical shaft of the drive; T_d and T_c are the time constants characterizing the viscous friction and rigidity of the mechanical shaft.

By (9) the transfer function of the object of the elastic drive is

$$W_0^{**}(s) = \frac{k_0(b_0 s^2 + b_1 s + 1)}{a_0 s^4 + a_1 s^3 + a_2 s^2 + a_3 s + 1}, \quad (10)$$

where $b_0 = T_2 T_c$; $b_1 = T_d$; $a_0 = T_1 T_2 T_c \delta_B \cdot T_T \cdot T_{EM}$;

$a_1 = [T_2 T_c + (T_1 + T_2)\delta_B T_d](T_T + T_{EM}) + T_1 T_2 T_C \delta_B$;

$a_2 = (T_T + T_{EM})[(T_1 + T_2)\delta_B + T_d] +$
$+ [T_2 T_C + (T_1 + T_2)\delta_B T_d]$;

$a_3 = (T_1 + T_2)\delta_B + T_d + T_T + T_{EM}$;

$T_1 = 1.5$; $T_2 = 10$; $T_d = 0.002$; $T_c = 0.0004$,

then the expression (10) is represented as follows

$$W_0^{**}(s) = \frac{0.022s^2 + 0.014s + 5.5}{0.0001s^4 + 0.0022s^3 + 0.1149s^2 + 1.352s + 1} \quad (11)$$

The transfer function of a discretely controlled object with z-operators, which corresponds to (11) is

$$W_0^{**}(z) = \frac{0.01z^3 - 0.01z^2 - 0.0086z + 0.01}{z^4 - 3.694z^3 + 5.903z^2 - 3.311z + 0.8025}. \quad (12)$$

By the frequency analysis we defined the transfer function of an optimal discrete regulator and its parameters:

$$D^{**}(z) = (10z - 8{,}8)/z. \quad (13)$$

Using (13) it is not difficult to obtain the transfer function of the closed asynchronous drive system taking into account the elastic properties of the mechanical shaft and its discrete control:

$$W^{**}(z) =$$
$$= \frac{0.01z^4 - 0.94z^3 + 0.001z^2 + 0.0875z - 0.088}{z^5 - 3.594z^4 + 5.015z^3 - 3.31z^2 + 0.9792z - 0.088}. \quad (14)$$

The roots of the characteristic equation (14) are: $z_1 = 0.15149$; $z_{2,3} = 0.8 \pm i0.0712$; $z_{4,5} = 0.92 \pm i\,0.227$. The dynamic stability of the drive system is observed in this case too, since $|z_i| < 1$.

Computer investigations of the considered drive showed that the duration of a transient process is 0.2 sec for a rigid shaft, and within 1 sec for an elastic shaft without any noticeable variations.

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