ISSN 2224-087X. Електроніка та інформаційні технології. 2017. Випуск 7. С. 49–56
Electronics and information technologies. 2017. Issue 7. P. 49–56

УДК 621.313

THE CONTROL SYSTEM OF TWO-MOTOR AC ELECTRICAL DRIVE WITH INDIVIDUAL REGULATORS OF SPEEDS

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In the paper dynamics of simplified scalar control system of two-motor electrical ac drive by frequency regulation is investigated. Mathematical model of the drive is constructed via electromagnetic processes agreement by taking into account elasticity of transmissions. The formulas to determine the optimal parameters of digital regulators for stator currents of the motors and speeds of the drive are given. Simulation results obtained in the Matlab are presented. It is established that considered system of the drive guarantees optimal dynamic characters as well as exact distribution of loading between the motors.

Key words: two-motor ac electrical drive, digital control, optimization of dynamics, proportional distribution of loading.

Introduction. Recently, due to the well-known advantages of an asynchronous motor in comparison with a DC motor in the practice of drives, it is actual to use a frequency-controlled asynchronous electric drive. However, on large precision-controlled technological machines, including paper-making machines, thyristor dc electric drives are still mainly used devices, as they are simpler and more reliable [1;2]. Frequency controlled ac drives on these machines (as on other powerful machines) are rare used since they are too complex and more unreliable control system [3;4]. Because presses of mechanisms of the paper-making machines have large inertial masses and action with a constant static moment, therefore it is possible for them to use a frequency controllable electric drive with a simplified two-circuit (from the speed and the current) control system. This is acceptable due to $U/f = const$, i.e. when the induction motor works with a constant magnetic flux and a constant torque.

Moreover, it is known that modern presses of paper machines on each working shaft have individual electric motors. Therefore, for these mechanisms we will investigate following simplified control system given on the Fig. 1.

On Fig. 1 there are used following notations: U_0-input signal; SR1, SR2, CR1 и CR2–digital controllers of speed and stator currents of the motors; FC1 and FC2-converters of frequency; AM1 and AM2- three-phase asynchronous electric motors; ZOH-zero order holds; ADC- analog-to-digital converter of signals; SS1 and SS2–sensors of speeds of electric motors; SC1 and SC2-sensors of stator currents of the motorsсенсоры статорных токов двигателей; T_0-sampling time of signals.

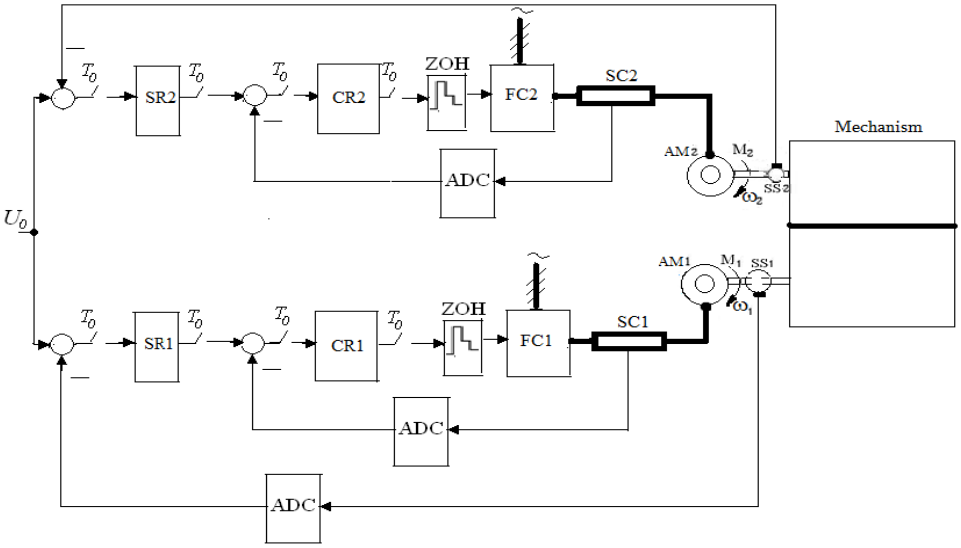


Fig. 1. Functional scheme of a two-motor frequency control drive

To the study of dynamic properties of introduced system of electric drive and with the aim build its structural scheme we consider equations of movement of the motors in the well established form of relative increments of variables:

$$K_{AM.i}\Delta f^* - \frac{\Delta\nu_i}{\delta_{B.i}} - \Delta\mu_{Ei} = T_i\frac{d(\Delta\nu_i)}{dt},\ i = 1,2, \tag{1}$$

where: $\Delta f^* = \dfrac{\Delta f}{f_B}$, $\Delta\mu_{Ei} = \dfrac{\Delta M_{E.i}}{M_{ST.iB}}$, $\Delta\nu_i = \dfrac{\Delta\omega_i}{\omega_B}$ -relative increments of variables- of frequency of the input voltages of the motors, of elastic moments of the shafts and of angle speeds of the motors; $K_{AM.i} = (1+\delta_{B.i})/\delta_{B.i}$ - coefficients of the transducers of the motors; $\delta_{B.i} = \Delta\omega_{B.i}/\omega_B$ - relative speed drops of the motors; $\Delta\omega_{B.i} = M_{ST.B.i}\cdot r'_{2.i}/c^2_{AM.i}$; $c_{AM.i} = U_{NOM}/\omega_{0NOM}$; $c_{AM.i} = U_{NOM}/\omega_{0NOM}$; $T_i = J_i\omega_B/M_{ST.B.i}$ -mechanical time constants of the motors.

While $U/f = const$, we have $\Delta f^* = \Delta\upsilon$, where $\Delta\upsilon = \dfrac{\Delta U}{U_B}$ - relative increments of stator voltages. Then equation (1) for the first motor can be written as follows:

$$K_{AM.1}\cdot\Delta\upsilon_1 - \frac{\Delta\nu_1}{\delta_{B.1}} - \Delta\mu_{E.1} = T_1\cdot\frac{d(\Delta\nu_1)}{dt}. \tag{2}$$

Similarly to equation (2), we can write its movement for the second motor, too :

$$K_{AM.2}\cdot\Delta\upsilon - \frac{\Delta\nu_2}{\delta_{B.2}} - \Delta\mu_{E.2} = T_2\frac{d(\Delta\nu_2)}{dt}. \tag{3}$$

The equation of movement of the press mechanism of the paper-making machine will have following view:

$$\sum_{i=1}^{2} K_{Li}\Delta\mu_{Ei} - \Delta\mu_{ST} = T_M \cdot \frac{d\Delta\nu_M}{dt}, \tag{4}$$

where: $K_{L1} = \frac{M_{ST1}}{M_{ST}}$, $K_{L1} = \frac{M_{ST1}}{M_{ST}}$ -coefficients of the loadings of the motors; $T_M = J_M\omega_B / M_{ST}$ - mechanical time constants of the mechanism.

If we take in consideration electromagnetic transient processes in the power electrical parts of the system (FC1-AM1 and FC2-AM2) with one equivalent electromagnetic time constants $T_{E.i} = (\omega_0 \cdot s_{k.i})^{-1}, i = 1;2$, also with time constants of the control systems FC1 and FC2 ($T_{FC.i}, i = 1;2$) then the system of differential equations whole power electromechanical part of the drive in relative increments of variables will have following view:

$$\begin{cases} \Delta\mu_i - \Delta\mu_{Ei} \dfrac{d(\Delta\nu_1)}{dt} = \dfrac{1}{T_i} \cdot \dfrac{d(\Delta\nu_i)}{dt}, \Delta\mu_i = K_{AM.i}\Delta\upsilon_i - \dfrac{\Delta\nu_i}{\delta_{B.i}}; \\ \sum\limits_{i=1}^{2} K_{L.i}\Delta\mu_{E.i} - \Delta\mu_{ST} = \dfrac{1}{T_M} \cdot \dfrac{d(\Delta\nu_M)}{dt}; \\ \Delta\mu_{Ei} = \dfrac{1}{T_{ci}} \cdot \int (\Delta\nu_i - \Delta\nu_M)dt + \dfrac{T_{di}}{T_{ci}} \cdot (\Delta\nu_i - \Delta\nu_M); \\ T_{Ei} \dfrac{d\Delta\mu_i'}{dt} + \Delta\mu_i' = K_{AM.i} \cdot \Delta\upsilon_i; \\ T_{FC.i} \dfrac{d\Delta\upsilon_i}{dt} + \Delta\upsilon_i = K_{FC.i} \cdot \Delta\upsilon_{CR.i},\ i = 1;2, \end{cases} \tag{5}$$

where: $\Delta\mu_i', \Delta\nu_M, \Delta\upsilon_{CR}$ -relative increments of the moment torque, angular speed of mechanism and output voltage of current regulator (CR); T_{di} and T_{ci} -time constants, characterizing elasticity and viscosity of mechanical transmission [3]; $K_{FC.i} = K_{FC.i}' \cdot \alpha_{FC}$, ($i = 1;2$)- transmission coefficients of frequency converters by representation in the form of relative increments; $K_{FC.i}' = \Delta E_{FC.B.i} / \Delta U_{CR.B.i}$ - coefficients of transmission of frequency converters; $\alpha_{FC} = U_{0.B} / E_{FC.B}$ - matching coefficient by the representation of equations in the form of relative increments;

Using operational form for the systems of differential equations (5) we can build detail structural scheme of the drive as follows.

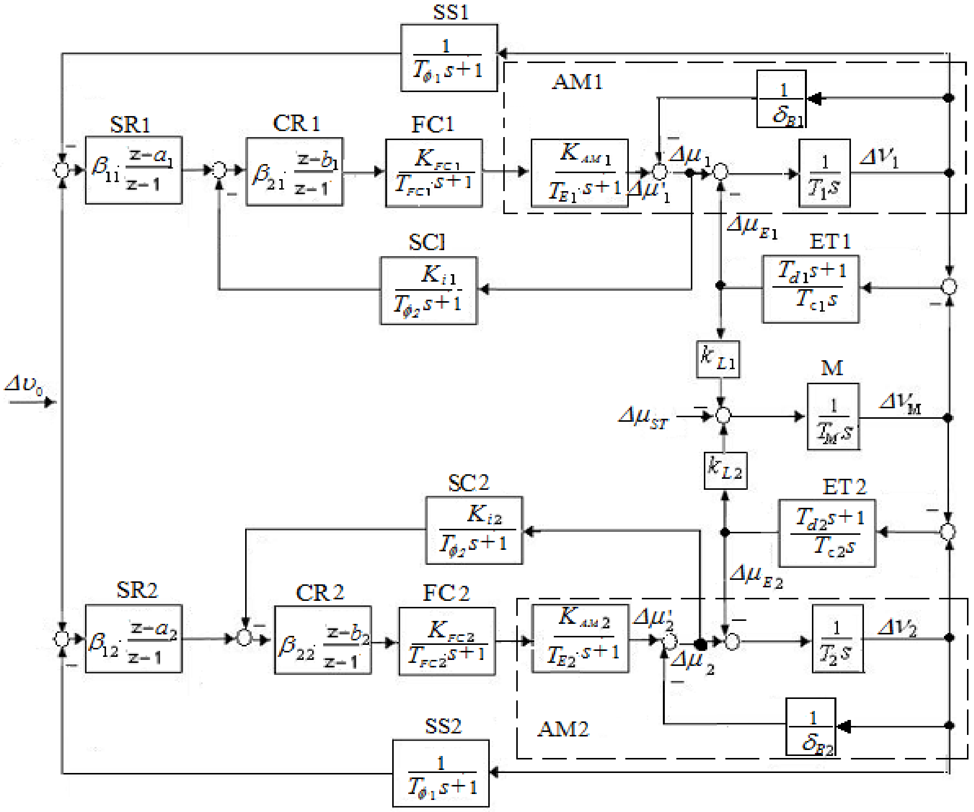


Fig. 2. Structural scheme of the two-motor asynchronous electric drive

On the Fig. 2 are used following notations: dynamic gains β_{11}, β_{12}, β_{21}, β_{22} and constants (a_1, a_2 and b_1, b_2) of the controllers, which are depending on the T_{Ei}, T_1, T_2, T_M and T_0; $T_{\varphi 1}$ and $T_{\varphi 2}$ are time constants of filters after sensors of the speeds and currents; $K_{i1,2} = K_i^{'} \cdot \alpha_i$ -coefficients of transition of current sensors; $K_i^{'} = U_{SC.B} / I_{AM.B}$; $\alpha_i = I_{AM.B} / U_{0.B}$.

On this scheme transfer functions of digital controllers (PI-type) are written via z-operators, where $z = 1 + T_0 \cdot s$, and $s = d / dt$ - Laplace operator.

To study characteristics of the system under consideration, the computer model was examined in the MatLab source (see Fig. 3). The following numerical values of the scheme are used: $T_{E1} = 0{,}1$ sec; $T_{\varphi 1} = 0.002$ sec; $K_{FC1} = 10$; $T_{FC1} = 0{,}01$ sec; $T_{\varphi 2} = 0.02$ sec; $T_{E2} = 0{,}07$ sec; $K_{FC2} = 10$; $T_{FC2} = 0{,}01$ sec; $T_M = 10$ sec.

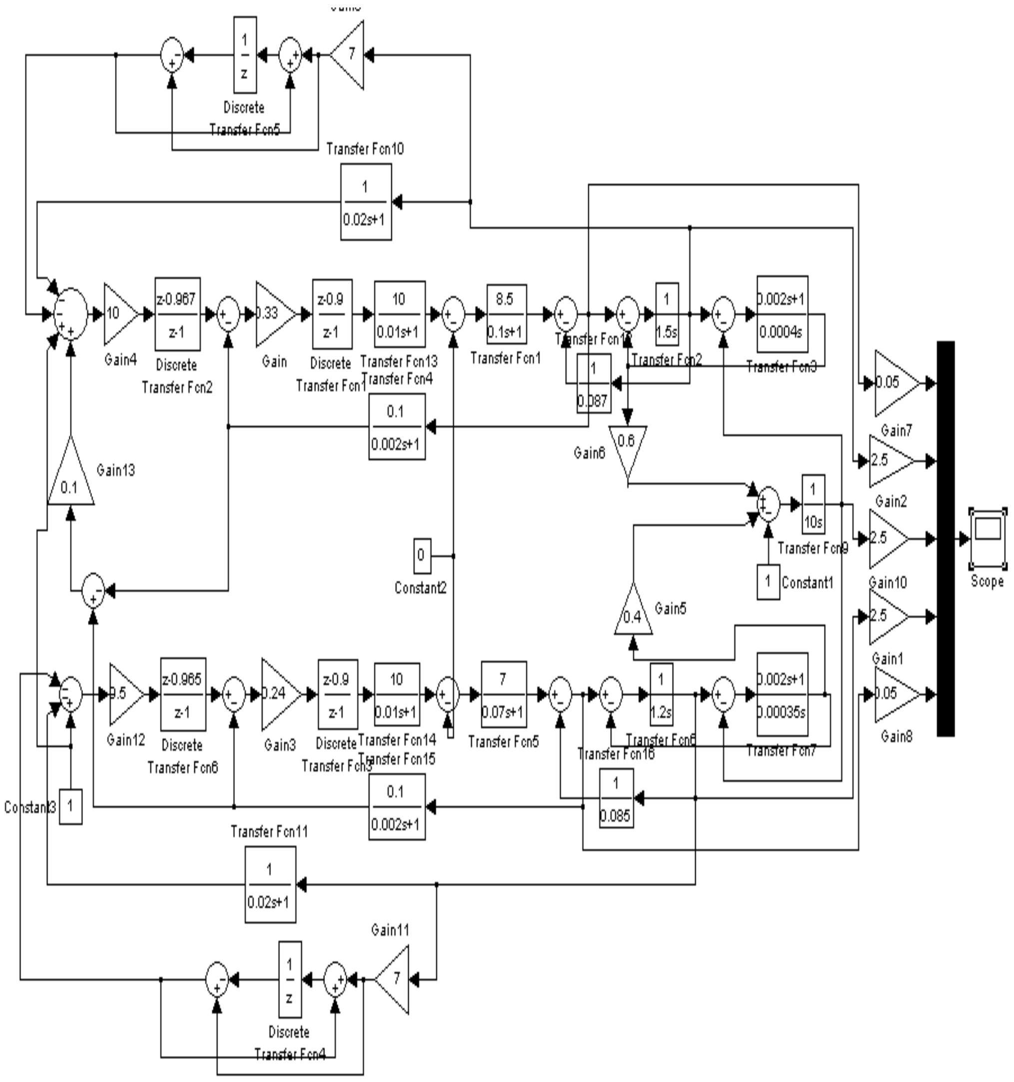


Fig. 3. Computer scheme of two-motor frequency electric drive

In the process of computer simulations of the drive system (fig.3) were established that in the current circuits ($\Delta\iota_i = \Delta\mu_i, i = 1;2$) influence of internal feedbacks of the motors through coefficients 1/0.087 and 1/0.085 from the speeds ($\Delta\nu_1$ and $\Delta\nu_2$) is negligible. Consequently, tuning of controllers (CR1 and CR2) can be done due to conditions of "module optima" [2; 3]. In this case parameters of CR1 were obtained according to the formulas:

$$\beta_{21} = \frac{T_{E1}}{2 \cdot k_{I1} \cdot k_{FC1} \cdot k_{AM1} \cdot T_{\Sigma 2}}; \quad \tau_{21} = T_{E1}, \qquad (6)$$

where $T_{\Sigma 2} = T_{FC1} + T_{\varphi 2} = 0.012$ sec; $\beta_{21} = 0.24$; $\tau_{21} = 0.1$ sec. In the digital performance of controller CR1 we should present its transfer function in the z-transformed form ($z = 1 + T_0 \cdot s$, [6,7]), i.e. as following:

$$W_{CR1}(z) = \beta_{21} \cdot \frac{z - b_1}{z - 1} = 0.24 \cdot \frac{z - 0.9}{z - 1} . \qquad (7)$$

Similarly to CR1, we can find parameters of CR2:

$$\beta_{22} = 0.24;\ b_2 = 0.9 . \qquad (8)$$

Tuning of speed controllers (SR1 and SR2) can be done according to “Symmetric Optima”, hence we have:

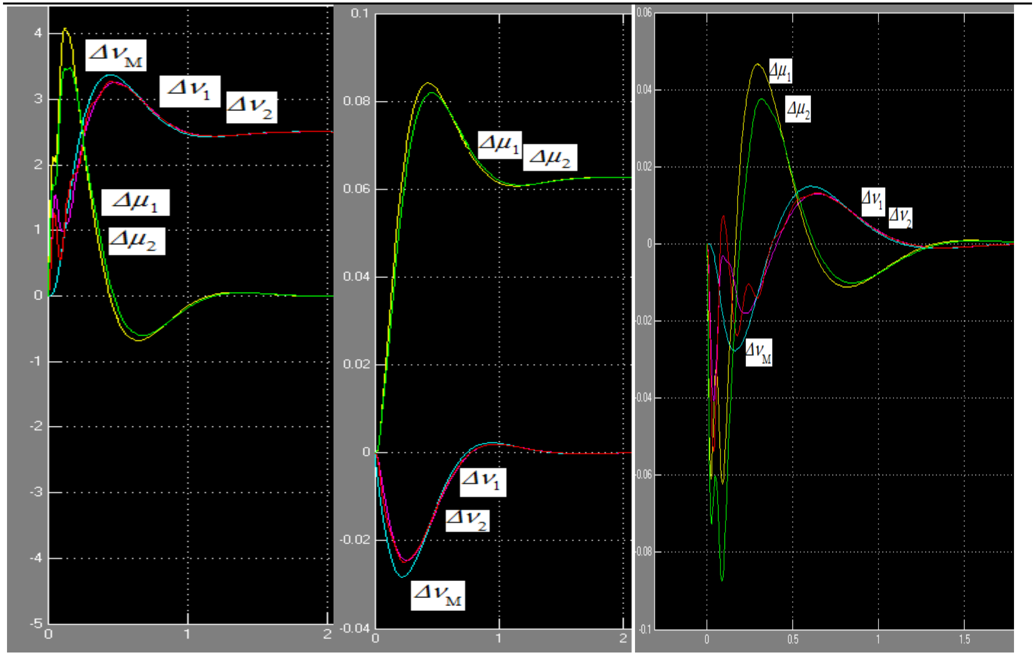
$$\beta_{11} = \frac{k_{i1} \cdot (T_1 + T_2)}{3{,}5 \cdot T_{\Sigma 1}};\quad \tau_{11} = 10 \cdot T_{\Sigma 1} , \qquad (9)$$

where $T_{\Sigma 1} = T_{\varphi 1} + T_{\Sigma 2} = 0.02 + 0.012 = 0.032$ sec. As result of calculations we obtain: $\beta_{11} = 10$; $\tau_{11} = 0.3$ sec. In the digital performance of controller SR, its transfer function will have following view:

$$W_{SR1}(z) = \beta_{11} \cdot \frac{z - a_1}{z - 1} = 10 \cdot \frac{z - 0.967}{z - 1} . \qquad (10)$$

Similarly, we obtain parameters of the SR2: $\beta_{12} = 9{,}5$; $a_2 = 0{,}965$.

Investigations of dynamics on the computer showed that without the introduction of flexible feedbacks on the speed of the motors to the inputs SR1 and SR2, the transient processes were unacceptably strongly oscillating (corresponding curves are not given).



a) b) c)

Fig.4. Curves of transient processes with correction under control action (a), at the load (b), with a step change voltage in the circuit (c)

After introducing SR1 and SR2 to the inputs of flexible feedback with the transfer function

$$W_1(s) = \frac{0.035 \cdot s}{0.005 \cdot s + 1} \Rightarrow W_1(z) = \frac{7(z-1)}{z+1} \tag{11}$$

dynamic characteristics were significantly improved as for input step type signal $\Delta\upsilon_0$ (Fig.4,a), as well as for loading step type signal $\Delta\mu_{ST}$ (Fig.4,b), also for stepwise voltage changing $\Delta\upsilon_S$ (Fig.4,c). Moreover, this system provides exact distribution of loading between the motors, since in the non-zero loading mode the condition $\Delta\mu_1 = \Delta\mu_2$ is satisfied (Fig.4,b).

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Стаття: надійшла до редакції 29.04.2017,
доопрацьована 04.05.2017,
прийнята до друку 12.05.2017.

СИСТЕМА КЕРУВАННЯ ДВОДВИГУНЕВОГО АСИНХРОННОГО ЕЛЕКТРОПРИВОДУ З ІНДИВІДУАЛЬНИМИ РЕГУЛЯТОРАМИ ШВИДКОСТЕЙ

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В роботі досліджена динаміка системи скалярного частотного керування дводвигуневого асинхронного електроприводу. Складена його математична модель, що враховує електромагнітні процеси у двигунах та пружні властивості механічних передач. Визначені формули для розрахунку оптимальних параметрів цифрових регуляторів статорних струмів двигунів і швидкостей. Наведені результати комп’ютерного дослідження перехідних процесів в середовищі MatLab. Показано, що розглянута система електроприводу забезпечує як оптимальні динамічні характеристики, так и точний розподіл навантаження між двигунами.

Ключеві слова: дводвигуневий частотний електропривод, цифрове керування, оптимізація динаміки, розподіл навантаження.

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