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DIGITAL CONTROL SYSTEM OF TWO-MOTOR
AC ELECTRICAL DRIVE BUILT BY
PRINCIPLES OF HARLAND

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In the paper, optimization of scalar control system of two-motor electrical ac drive with individual regulators of speed is investigated. Structural scheme of the drive is constructed via electromagnetic process agreement taking into account elastic shaft. The expressions for the optimal parameters of digital regulators for stator currents of the motors and speed of the drive are given. Modelling results obtained on the computer are given. The considered system of ac drive provides optimal dynamic character as well as automatic distribution of loading between the motors.

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

1.INTRODUCTION

Recently, due to the well-known advantages of an ac motor in comparison with a dc motor in the practice of drives, it is topical 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, i.e. vector controlled ac drives on these machines (as on other powerful machines) are seldom used since they are a too complex and more unreliable control system [3], [4]. Presses of mechanisms of the paper-making machines have large inertial masses and action with a constant static moment ($M_{sr} = const$); therefore, it is possible for them to use a frequency controllable electric drive with a simplified two-circuit (from the speed and the current) scalar control system. This is acceptable due to $U/f = const$, i.e. when, the induction motor works with a constant magnetic flux ($\Phi = const$) and a constant torque ($M = const$).

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 in the paper the following simplified control system given in Fig. 1.

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

In Fig. 1 the following notations are used: U_0 is input signal; SR1, SR2, CR1 and CR2 are digital regulators of speed and stator currents of the motors; FC1 and FC2 are converters of frequency; AM1 and AM2 are three-phase asynchronous electric motors; ZOH is zero order holds; ADC denote analog-to-digital converter of signals; SS1 and SS2 are sensors of speeds of electric motors; CT1 and CT2 are sensors of stator currents of the motors; T_0 denotes sampling time of signals.

2. EQUATIONS OF DYNAMICS OF THE DRIVE

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

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

where: $\Delta f^* = \frac{\Delta f}{f_B}$, $\Delta \mu_{Ei} = \frac{\Delta M_{E.i}}{M_{ST.iB}}$, $\Delta v_i = \frac{\Delta \omega_i}{\omega_B}$ are relative increments of variables

of frequency of the input voltages of the motors, of elastic moments of the shafts and of angle speed of the motors; $K_{AM.i} = (1 + \delta_{B.i}) / \delta_{B.i}$ are coefficients of the transducers of the motors; $\delta_{B.i} = \Delta \omega_{B.i} / \omega_B$ are relative speed drops of the motors; $\Delta \omega_{B.i} = M_{ST.B.i} \cdot r'_{2.i} / c_{AMi}^2$; $c_{AMi} = U_{NOM} / \omega_{NOM}$; $T_i = J_i \omega_B / M_{ST.B.i}$ are mechanical time constants of the motors.

$U / f = const$, we have $\Delta f^* = \Delta v$, where $\Delta v = \frac{\Delta U}{U_B}$ are relative increments

of stator voltages. Then equation (1) for the first motor can be written as follows:

$$K_{AM,1} \cdot \Delta v_1 - \frac{\Delta v_1}{\delta_{B,1}} - \Delta \mu_{E,1} = T_1 \cdot \frac{d(\Delta v_1)}{dt}, \quad (2)$$

Similarly to equation (2), it is possible to write its movement for the second motor:

$$K_{AM,2} \cdot \Delta v_2 - \frac{\Delta v_2}{\delta_{B,2}} - \Delta \mu_{E,2} = T_2 \cdot \frac{d(\Delta v_2)}{dt}. \quad (3)$$

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

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

where $K_{L1} = \frac{M_{ST1}}{M_{ST}}$, $K_{L2} = \frac{M_{ST2}}{M_{ST}}$ are coefficients of the loadings of the motors;

$T_M = J_M \omega_B / M_{ST}$ is mechanical time constant of the mechanism.

If we take into consideration electromagnetic transient processes in the power electrical parts of the system (FC1-AM1 and FC2-AM2) with 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 of the whole power electromechanical part of the drive in relative increments of variables will have the following form:

$$\left\{ \begin{array}{l} \Delta \mu_i - \Delta \mu_{Ei} \frac{d(\Delta v_i)}{dt} = \frac{1}{T_i} \cdot \frac{d(\Delta v_i)}{dt}, \Delta \mu_i = K_{AM,i} \Delta v_i - \frac{\Delta v_i}{\delta_{B,i}}; \\ \sum_{i=1}^2 K_{Li} \Delta \mu_{Ei} - \Delta \mu_{ST} = \frac{1}{T_M} \cdot \frac{d(\Delta v_M)}{dt}; \\ \Delta \mu_{Ei} = \frac{1}{T_{ci}} \cdot \int (\Delta v_i - \Delta v_M) dt + \frac{T_{di}}{T_{ci}} \cdot (\Delta v_i - \Delta v_M); \\ T_{Ei} \frac{d\Delta \mu_i'}{dt} + \Delta \mu_i' = K_{AM,i} \cdot \Delta v_i; \\ T_{FC,i} \frac{d\Delta v_i}{dt} + \Delta v_i = K_{FC,i} \cdot \Delta v_{CR,i}, i = 1; 2 \end{array} \right. \quad (5)$$

where $\Delta \mu_i'$, Δv_M , Δv_{CR} are relative increments of the moment torque, angular speed of mechanism and output voltage of current regulator (CR); T_{di} and T_{ci} are time constants characterising elasticity and viscosity of mechanical transmission [3]; $K_{FC,i} = K'_{FC,i} \cdot \alpha_{FC}$, $i = 1; 2$ are transmission coefficients of frequency converters

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

In the process of computer simulations of the drive system (Fig. 3) it has been established that in the current circuits ($\Delta i_i = \Delta \mu_i, i = 1; 2$) influence of internal feed-backs of the motors through coefficients $1/0.087$ and $1/0.085$ from the speed (Δv_1 and Δv_2) is negligible.

Consequently, tuning of regulators (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:

$$\beta_{21} = \frac{T_{E1}}{2 \cdot k_{\mu 1} \cdot k_{FC1} \cdot k_{AM} \cdot T_{\Sigma 2}}; \quad \tau_{21} = T_{E1}, \quad (6)$$

where $T_{\Sigma 2} = T_{FC1} + T_{\phi 2} = 0.012$, sec.; $\beta_{21} = 0.24$; $\tau_{21} = 0.1$, sec. In the digital performance of regulator CR1 we should present its transfer function in the z-transformed form ($z = 1 + T_0 \cdot s$, [5], [6]), i.e., as follows:

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

Similarly to CR1, we can find parameters of CR2:

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

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

$$\beta_{11} = \frac{k_{i1} \cdot (T_1 + T_2)}{3.5 \cdot T_{\Sigma 1}}; \tau_{11} = 10 \cdot T_{\Sigma 1}, \quad (9)$$

where $T_{\Sigma 1} = T_{\phi 1} + T_{\Sigma 2} = 0.02 + 0.012 = 0.032$ sec. As a result of calculations, we obtain: $\beta_{11} = 10$; $\tau_{11} = 0.3$ sec. In the digital performance of regulator SR1, its transfer function will have the following form:

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

Similarly, we obtain parameters of 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).

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

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

dynamic characteristics were significantly improved as for input step type signal ΔU_0 (Fig. 4a), as well as for loading step type signal $\Delta \mu_{ST}$ (Fig. 4b), also for stepwise voltage changing ΔU_S (Fig. 4c). 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. 4b).

4. CONCLUSIONS

1. For modern presses of paper-making machines, a simplified control system has been developed for a two-motor frequency-controlled ac electric drive with individual speed regulators and stator motor currents.
2. A mathematical model of the dynamics of the electric drive system has been obtained. As a result of the frequency analysis of the drive system object, expressions to determine the optimum parameters of digital regulators have been given. By modelling such kind of ac drive system on a computer transient characteristics are obtained, which are similar to dc thyristor drive ones with elastic links.
3. The proposed control scheme for a two-motor frequency drive provides an automatic load distribution between the motors by means of cross-links.

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DIVDZINĒJU MAINSTRĀVAS ELEKTROPIEDZIŅAS DIGITĀLĀ VADĪBAS SISTĒMA, KAS UZBŪVĒTA PĒC HARLANDA PRINCIPIEM

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K o p s a v i l k u m s

Darbā tiek pētīta divdzinēju mainstrāvas elektropiedziņas ar frekvences regulēšanu vienkāršotās skalārās vadības sistēmas dinamika. Piedziņas matemātiskais modelis tiek veidots, izmantojot elektromagnētisko procesu, ņemot vērā pārnenumu elastību. Rakstā sniegti vienādojumi, lai noteiktu digitālu regulatoru optimālos parametrus dzinēju statora strāvai un piedziņas ātrumam. Darbā arī atspoguļoti simulācijas rezultāti, kas iegūti Matlab. Konstatēts, ka piedziņas sistēma nodrošina optimālu dinamisko raksturu, kā arī precīzu slodzes sadali starp dzinējiem.

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