experience of analogous equipment designing and tried to reduce the process costs to a minimum in their solutions according to the above given principles of rolling equipment designing.

We ere ready to customize these solutions at any place of the World and hope that the above information will help our eventual Customers in their business-plans developments for the similar objects construction.

Automatic drive systems of transport-technological complexes

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The increase in ironworks production has determined the necessity of introduction of continuous production lines and up-to-date automatic transport-technological complexes ATTC. To secure improved reliability of the equipment applied in ATTC, particularly conveyor units, the transition to multi-motor electric drives is taking place to provide more uniform load distribution along the routing of conveyor systems.

The multi-motor electric drive is used when the routing of conveyor systems is very long and complex [1]. Its application facilitates the operation of a conveyor mechanical section providing more equal distribution of moving force along the conveyor route. So, for instance, from the orthographic epure moving force it is obvious that at the moment of transition from a single-motor electric drive to a twin-motor one (provided that the load is equally distributed between electric motors) the maximum pull is reduced by half. The equal load distribution between motors is one of the basic problems to be solved in the course of conveyor system multi-motor drive designing and operation (Fig. 1). The conventional approach to solving the problem is application of uniform motors with similar nominal parameters and an appropriate location of motors in the conveyor system [2]. However, considering motor technological parameter spread, as well as a nonoptimal selection of motor location caused by lack of space in shop-floor conditions, calculating errors, etc., as a rule it is impossible to achieve uniform motor operation in multi-motor drives of conveyor units only due to the above-mentioned measures. As the investigations conducted on five-motor conveyor PK-1 of "Kirovsky zavod" industrial association have shown [3], total active power ranged within 20 % (from 8 to 10 kW) during operation time, yet each motor power ranged within wider variation limits. Load ratio of two motors out of 5 during the whole testing period (4 days) made 20–50 % from the other 3 motors loading. Similar load distribution results in the need for overmotoring of drive and causes mechanical failures, decrease in motor efficiency and power factor, etc. It is necessary to create a special system of automatic load control to balance load in individual motors. Induction motors (IM) with phase-wound rotor, IM with thyristor control, DC machines, a drive with variable reduction gearbox ratio and some other drive types can be used in the multi-motor drive with automatic load balancing of individual motors, but the direct-current drive has not been considered on the grounds of drive reliability.

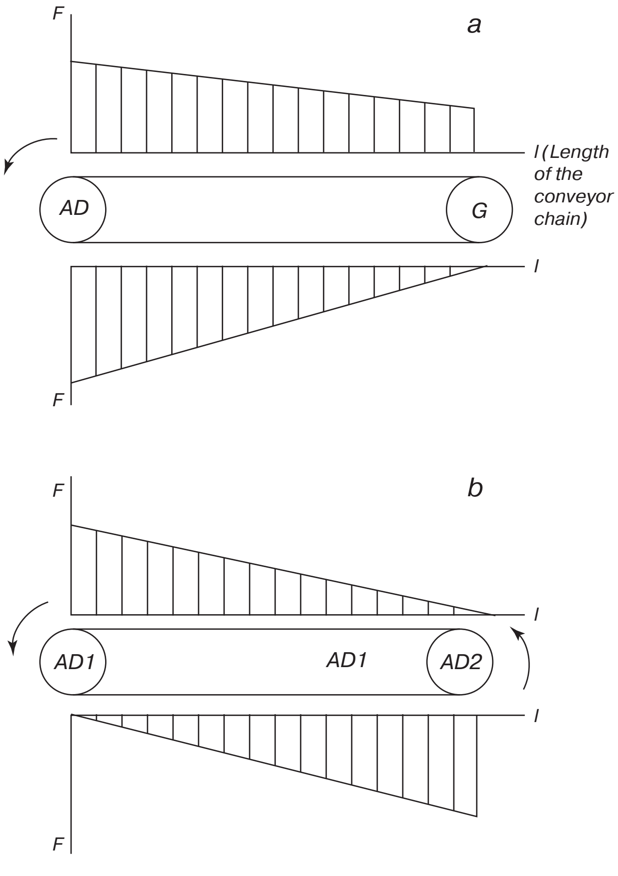

Fig. 1. Moving force distribution diagram (*G* — Idle Gear)

The given paper presents the results obtained when developing the following types of conveyor electric drives, viz. the electric drive with IM use with a squirrel-cage rotor and variable parameters [4], the electric drive with an induction squirrel-cage motor and differential speed reduction device controlled by DC machines [3, 5, 6] .

The application of induction motors with squirrel-cage rotor in electric drive diagrams permits to increase the electric drive reliability sufficiently and reduce its cost due to using simpler control equipment.

It is well-known that one of induction motor disadvantages is its low regulating capability (as compared to direct-current motor). A rotor with variable parameters is used to improve the induction squirrel-cage motor speed regulation effectiveness that makes it possible to achieve speed-torque characteristic without pronounced maximum. This speed-torque characteristic renders possible to regulate motor speed by changing the value of primary voltage under satisfactory cost-performance ratio [4]. The square-cage induction motor with shading coils (Fig. 2) is used in the conveyor electric drive with automatic load distribution. The above-mentioned shrouds are made of sm 3 cast steel.

Such rotor construction is characterized by good processibillity during stock motors renovation. The shrouds create additional variable active-inductive resistance in the rotor circuit, and, on account of this resistance dependence on slip and primary voltage value, it makes possible to eliminate partially the maximum speed-torque characteristic and lower the value of starting current.

The inflexibility of regulating characteristics in electric drive circuit diagrams is achieved owing to linear feedbacks of current linkage and primary voltage.

The electric circuit diagram of dual-motor electric drive PK-3 is presented in Fig. 3, AD1 motors and AD2 motors are mechanically interconnected by a conveying chain, long-term rotation speed variation of both motors is carried out by the moving coupled potentiometer sliders ПУ1 and ПУ2 which help to regulate the voltage value impressed from the rectifiers ВУ1 and ВУ2 to control winding of MA1 and MA2 magnetic amplifiers.

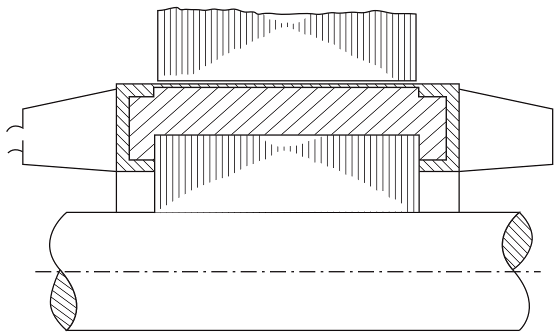

Fig. 2. The design of the rotor of the adjustable square-cage induction motor with shielded poles

Load distribution between the motors proceeds as a result of IM positive feedback. Meanwhile, a signal proportional to the current consumed by IMG is given to field winding of magnetic amplifier MA2 supplying AD2 and contrariwise. In case of AD1 load increase AD1 stator current also increases, and due to positive feedback impact the voltage across field winding MA2 increases as well. Consequently MA2 output voltage and AD2 stator current increase, that results in the increase in AD2 take of overall load. In case of AD1 off-loading or AD2 load variation the impact of positive feedback of stator current linkage is similar to the above-mentioned one. Stator current-feedback circuit comprises a current transformer (TT1 for motors AD1

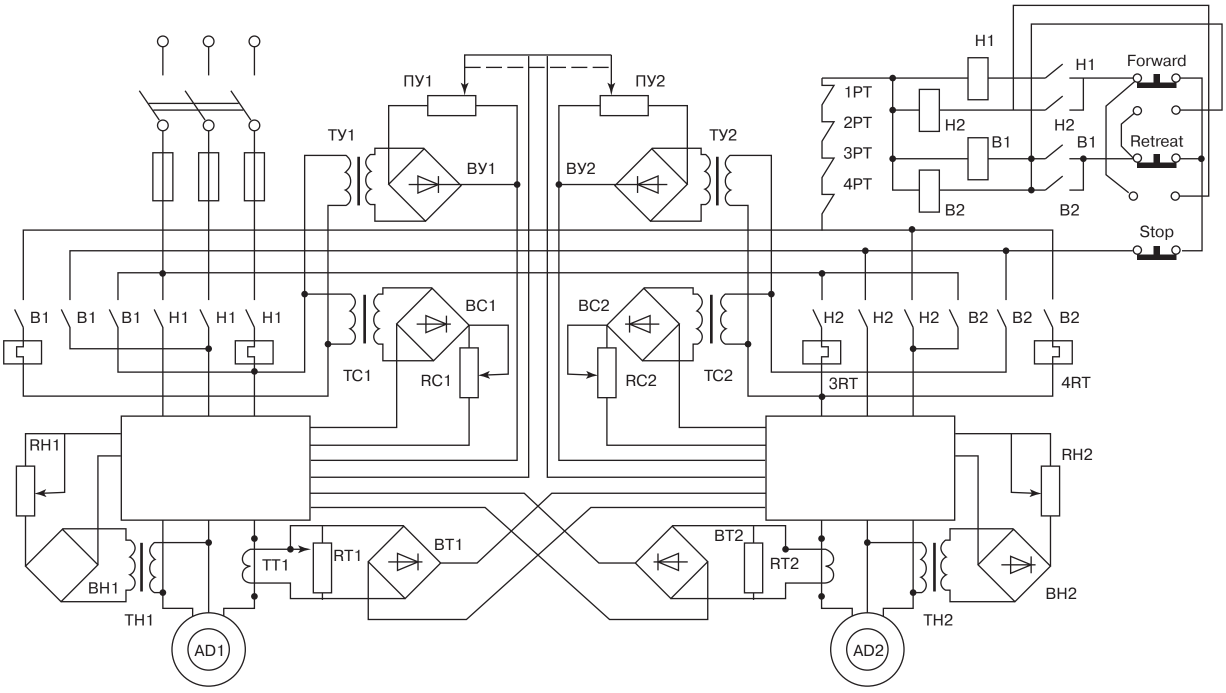

Fig. 3. The electric circuit diagram of PK-3 dual-motor electric drive with automatic load distribution

and TT2 for AD2), a variable resistor (RT1, RT2) and a rectifier (BT1, BT2). Variable resistors RT1 and RT2 serve for feedback depth adjustment. RT1 and RT2 values differ from each other, and their final values are chosen during adjustment, besides, the electric drive comprises automation scheme controlling start, reverse and stop of the electric drive and the circuit: negative feedback on primary voltage wraparound every motor for the purpose of getting the relevant motor ratings.

The main advantages of the above-described electric drive is high reliability determined by using such elements as induction motor and magnetic amplifier, good control characteristic and relatively low cost.

The electro-mechanical drive (EMD) is the second type of the newly developed electric drive of conveyor systems. EMD systems provide the conveyor drive operation in two modes: mode A — with defined load distribution between the motors of conveyor machines M1 and M2, mode B- with natural load distribution between the motors M1 and M2.

The mode selection can be made both by an operator and automatically, furthermore A-B mode change can be anticipated in case of a fault inception in the EMD system. In accordance with the scheme, three differential shafts RD (input, regulating and output) are connected respectively with driven induction square-cage motor M1, regulating direct-current machine M3 and operational voltage-dropping resistor RKTSN1. The second operating motor induction square-cage motor M2 is directly connected with reducer RKTSN2. The output shaft of RKTSN reductor is connected with the leading conveyor sprockets.

The defined load distribution between motors M1 and M2 is achieved by smooth variation of n3 rotation frequency of the regulating machine M3. Thereby frequency n_p at the differential speed reduction device output RD is determined by the algebraic sum of frequencies n1 and n3. In steady state mode frequency n_p is equal to frequency n2 of the drive with non-adjustable induction motor M2. Rotation frequency n2 sets the motion speed of the conveyor line. np frequency regulation by n3 variation is equivalent to the drift of M2 speed-torque characteristic in parallel to itself, that results in load distribution between motors M1 and M2. With the defined even load distribution the rotation frequency of machine M3 is determined by the difference in the rated slip between machines M1 and M2. At that automatic load distribution is set by means of watt transducers D1 and D2. The control signal proportional to the difference in watt transducers D1 and D2 signals, comes from comparison element E at the amplifier input U which is a part of thyristor converter LT. In response to this signal the load at the thyristor converter output and correspondingly the rotation frequency of the regulating machine M3 vary in such a way that it makes possible to minimize the difference between the defined and actual distribution of wattful currents of motors M1 and M2.

Electromagnetic brake *T* is installed at the adjustable differential shaft to improve reliability of EMD system. When a fault inception takes place in the regulating machine M3 or converter LX, the regulating shaft RD is slowed down by means of the brake *T*, and the conveyor line starts operating with natural load distribution between the engines M1 and M2. The dynamic processes have a great impact on the operation of the multi-motor drive of conveyor systems. During investigations of five-motor drive of conveyor PK-1 of "Kirovsky zavod" industrial association it has been found that there is continuous load transfer between motors; the drive operates in dynamic mode, and short-time and not inconsiderable overstressing takes place at the individual sections of the conveyor line. It makes the operating conditions of the conveyor mechanical section much worse and causes an early wear of haulage chain, that in its turn increases the conveyor down time. That's why during designing the multi-motor conveyor drive much attention was paid to the development of the engineering methods of multi-motor conveyor drives dynamic analysis. At that there is an urgent necessity nowadays not only to create design procedures that allow making in-depth dynamic analysis on the basis of complex up-to-date methods application, which make allowance for nonlinear effects of electrical and mechanical drive sections, but also simplified methods of dynamic analysis for preliminary dynamic analysis at the stage of schematic design; the technique for simplified dynamic analysis of multi-motor drives of conveyor systems is given below.

The non-adjustable multi-motor drive of conveyor represents n individual electric drives operating on the overall load — dual-duty overhead conveyor. As a rule, asynchronous drive is used as a PKT electric drive. The equation of an individual asynchronous drive can be written as follows:

$$I\frac{d\omega}{dt} = M_{mot}(\omega, U) - M_s, \qquad (1)$$

where ω — rotational speed of the electric drive output shaft; M_{mot} — moment (torque), developed by induction motor; M_s — resisting moment (of load), reduced to the motor shaft; $U = U_y / U_{y\,\max}$ — control voltage AD in a dimensionless form.

The induction motor torque represents a nonlinear function of actual parameters and, which can be approximated by Kloss formula without regard to transient phenomena in windings IM

$$M_{mot}(\omega, U) = M_K \frac{2SS_C}{S^2 + S_C^2} \qquad (2)$$

where $S = -\omega/\omega_0$; ω_0 — IM synchronous speed; S_C – the critical values of torque and slip.

In a common case the control voltage U is determined from differential equation

$$T\frac{dU}{dt} + U = KU_1, \qquad (3)$$

The equation (3) is considered when the control voltage is taken from the amplifier output with response time $T_y = T$

and a coefficient of amplification $K_y = K$ or when it is necessary to take into account fast-time constants that determine transient phenomena in IM. Accordingly the equations of the 1st electric drive with IM can be written as follows

$$I' \frac{d\omega^i}{dt^i} = M^i_{mot}(\omega^i, U^i) - M^i_s$$

$$T\frac{dU^i}{dt} + U^i = K^i U^i, \qquad (4)$$

and represent a nonlinear system of ordinary differential second-order equations.

The resisting moment of the 1st electric drive Mc is a part of the joint moment developed by multi-motor drive, undertaken by the 1st electric drive. The relation of the joint moment developed by multi-motor drive and the moment applied by an individual drive is expressed by the equation

$$\sum_{i=1}^{n} M^i_s = M_s. \qquad (5)$$

At that M_s value corresponds to a certain function of conveyor speed.

To determine the exact function pattern it is necessary to carry out a special investigation. The data available [2, 3] allow making a conclusion that the value Mc is determined for the most part by the forces of unlubricated friction, and in this case the jump (leap) of resisting moment when starting is smoothed due to taking-up of clearance in the conveying chain.

The resisting moment peak exceeds its steady-state value by 10–15 % as it is indicated in [3]. The approximate dependence of PTK drive resisting moment on conveyor speed is shown in relation 5.

For non-adjustable electric drive PTK in operation conditions the value of control voltage remains constant and the resisting moment is perturbance. At low perturbance value IM speed variation range is insignificant and, dependence on can be considered linear. At that

$$M^i_{mot} = M - \beta^i\omega^i,$$

where β^i — hardness of speed-torque characteristic of *i*-engine.

V and ω^i is angle speed of *i*-engine.

Taking into consideration transfer functions

$$W_i(S) = \frac{1}{T_i S + 1}, \qquad (6)$$

where $T_i = I^i/\beta^i$ after simple transformations we obtain

$$\Phi_1(S) = \frac{M^i_{mot}(S)}{M_c(S)} = (1 - W_2(S))\cdot\frac{W_1(S)}{1 - W_1(S)\cdot W_2(S)} \qquad (7)$$

Substituting (6) in (7) we will have

$$\Phi_1(S) = \frac{K_1}{\tau S + 1}. \qquad (8)$$

Similar expressions we will obtain for M2:

$$\Phi_2(S) = \frac{M^2_{mot}(S)}{M_c(S)}.$$

In a more common case for n motor drive we have

$$M^i_{mot}(S) = W_1(S)\cdot[M_c(S) - \sum_i^n M^i_{mot}(S)],\ i = 1, 2, ..., n.$$

The previous expression we put down as follows:

$$\left.\begin{array}{l}
\Phi_1(S) + W_1(S)\Phi_2(S) + W_1(S)\Phi_3(S) + ... + W_1(S)\Phi_n(S) = W_1(S) \\
W_2(S)\Phi_1(S) + \Phi_2(S) + W_2(S)\Phi_3(S) + ... + W_2(S)\Phi_n(S) = W_2(S) \\
\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
W_n(S)\Phi_1(S) + ... + W_n(S)\Phi_{n-1}(S) + \Phi_n(S) = W_n(S)
\end{array}\right\} \qquad (9)$$

where is defined by (6), and $\Phi_i(S) = \dfrac{M^i_{mot}(S)}{M_c(S)}$

According to Cramer's rule the system solution has the following view

$$\Phi_i(S) = \frac{\Delta^i(S)}{\Delta(S)} \qquad (10)$$

$$\Delta S = \begin{vmatrix}
1 & W_1(S) & ... & W_1(S) \\
W_2(S) & 1 & ... & W_2(S) \\
... & ... & ... & ... \\
... & ... & ... & ... \\
W_n(S) & W_n(S) & ... & 1
\end{vmatrix} =$$

$$= \prod_{i=1}^{n} W_i(S)\cdot\begin{vmatrix}
\frac{1}{W_1(S)} & 1 & ... & 1 \\
1 & \frac{1}{W_1(S)} & ... & 1 \\
... & ... & ... & ... \\
... & ... & ... & ... \\
1 & 1 & ... & \frac{1}{W_n(S)}
\end{vmatrix},$$

$$\Delta^i(S) = \begin{vmatrix}
1 & W_1(S) & W_1(S) & W_1(S) & ... & W_1(S) \\
... & ... & ... & ... & ... & ... \\
W_{i-1}(S) & 1 & W_{i-1}(S) & W_{i-1}(S) & ... & W_{i-1}(S) \\
W_i(S) & W_i(S) & 1 & W_i(S) & ... & W_i(S) \\
... & ... & ... & ... & ... & ... \\
W_n(S) & W_n(S) & W_n(S) & W_n(S) & ... & 1
\end{vmatrix} =$$

$$= \prod_{i=1}^{n} W_i(S) \begin{vmatrix} \frac{1}{W_1(S)} & \ldots & 1 & 1 & 1 & \ldots & 1 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 1 & \frac{1}{W_{i-1}(S)} & 1 & \ldots & \ldots & \ldots & 1 \\ 1 & \ldots & 1 & \frac{1}{W_i(S)} & 1 & \ldots & 1 \\ 1 & \ldots & 1 & 1 & \frac{1}{W_{i+1}(S)} & \ldots & 1 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 1 & 1 & 1 & 1 & 1 & \ldots & \frac{1}{W_n(S)} \end{vmatrix}, \Delta^i(S) \neq 0.$$

Making use of (10) we will get the expression for transfer function of the first motor in three-motor drive PTK. Hence

$$\Phi_i(S) = \frac{\Delta^i(S)}{\Delta(S)} = \frac{\begin{vmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & \frac{1}{W_3(S)} \end{vmatrix}}{\begin{vmatrix} \frac{1}{W_1(S)} & 1 & 1 \\ 1 & \frac{1}{W_2(S)} & 1 \\ 1 & 1 & \frac{1}{W_3(S)} \end{vmatrix}} =$$

$$= W_1(S) \cdot \frac{1 + W_2(S)W_3(S) - W_2(S) - W_3(S)}{1 + 2W_1(S)W_2(S)W_3(S) - W_1(S)W_3(S) - W_1(S)W_3(S)}.$$

By taking $W_i(S) = \frac{1}{T_i S + 1}$, $T_i = \frac{I^i}{\beta^i}$; we find

$$\Phi_1(S) = \frac{K_1}{\tau S + 1},$$

$$K_1 = \frac{T_2 T_3}{T_1 T_2 + T_1 T_3 + T_2 T_3} = \frac{\beta^1}{\beta^1 + \beta^2 + \beta^3},$$

where

$$\tau = \frac{T_1 T_2 T_3}{T_1 T_2 + T_1 T_3 + T_2 T_3} = \frac{I}{\beta^1 + \beta^2 + \beta^3}$$

From (7), (9) it follows that response time τ determining the time of transient phenomena in multi-motor drive decreases as cooperated to one-engine drive (with the similar equivalent moments of inertia). When perturbance is in action, as it has been indicated load moment variation stands for it, the 1st engine in multi-motor drive acts as the first-order aperiodic link, and, therefore it is steady under different values and provided that

$$\sum_{i=1}^{n} \beta^i > 0. \qquad (11)$$

The inequation (11) represents the necessary and sufficient condition of the individual drive stability on the assumption of the equivalent moments of inertia, equation. If the given equation is not executed, than the inequation (11) takes on form:

$$\sum_{i=1}^{n} I_1 I_2 \ldots I_{i-1} \beta_i I_{i+1} I_n > 0.$$

It is possible to prove that this conclusion doesn't change with an allowance for speed-torque characteristic. We will demonstrate it by the example of dual-motor drive ПТК with provision for nonlinearity of AD speed-torque characteristic (relation 7). it is obvious from the figure that output signals NE come to NE input through the filters $1/I^i S$. Thereby the conditions for the harmonic linearization (10) method validity are met.

According to (2) the equation NE has the following view

$$y = K \frac{(1 - ax)S_k}{(1 - ax)^2 + S_k^2},$$

where $K = 2MnU^2 = const$ — coefficient of proportionality in operation conditions,

$$a = \frac{1}{\omega_0} = const,\ y = M_{mot},\ x = \omega.$$

The complex transfer constant of NE is determined by the expression

$$W(A, j\omega) = q(A, \omega) + jq'(A, \omega) = R(A, \omega)e^{j\varphi(A, \omega)},$$

where $q(A, \omega)$, $q'(A, \omega)$ — the coefficients of harmonic linearization.

$$R(A, \omega) = \operatorname{mod} W(A, \omega) = \sqrt{q^2(A, \omega) + (q'(A, \omega))^2}.$$

The coefficients of harmonic linearization can be calculated according to the following expressions:

$$\varphi(A, \omega) = \arg W(A, \omega) = \operatorname{arctg}\left(\frac{q'(A, \omega)}{q(A, \omega)}\right)$$

$$q(A, \omega) = \frac{1}{3}\left[\Phi(x_0 + A) - \Phi(x_0 - A) + \Phi\left(x_0 + \frac{A}{2}\right) - \Phi\left(x_0 - \frac{A}{2}\right)\right.$$

$$q(A, \omega) = 0$$

$$q(A, \omega) = \frac{1}{3}\left[\Phi(x_0 + A) - \Phi(x_0 - A) + 2\Phi\left(x_0 + \frac{A}{2}\right) - 2\Phi\left(x_0 - \frac{A}{2}\right)\right.,$$

where $x = x_0 + A\sin\omega t$; $\Phi(A) = K\dfrac{(1 - aA)S_k}{(1 - aA)^2 + S_k^2}$.

The structural circuit of linearized twin-motor drive PTK is represented in relation 8. It is easy to notice that it differs from the structural circuit only in one respect: the hardness of speed-torque characteristics of drive motors β^1 and β^2 are replaced with $-q_1(A_1)$ and $-q_2(A_2)$ hence, the expression (7) remains unchanged, and the values of K_1 and are determined as follows:

$$K_1 = \frac{I^2 q_1(A_1)}{I^1 q_2(A_2) + I^2 q_1(A_1)},\ K_1 = \frac{I^1 I^2}{I^1 q_2(A_2) + I^2 q_1(A_1)}.$$

The motor rigidity in this case is determined by positive definiteness and, therefore the inequation

$$I^1 q_2(A_2) + I^2 q_1(A_1) > 0$$

similar to (10), and represents the necessary and sufficient condition of stable operation of a motor in dual-motor drive PTK.

In the preceding analysis of multi-motor drive operation PTK it was assumed that the rotation frequency of nth motor can take any values from the given range of rotation frequency variation without dependence on other motors frequency rate. This hypothesis is equivalent to the statement about absolute stretchability of a conveying chain and correct only when taking-up of clearance, i. e. in the case when tension stations have no restrictors. In other borderline case, when a conveying chain is considered to be absolutely stiff, the transient equation is:

$$I_\Sigma \frac{d\omega}{dt} = M_{\text{пр}}(\omega, U^i) - M_s, \qquad (12)$$

where $I_\Sigma = \sum_{i=1}^{n} I^i$, $M_{\text{пр}}(\omega, U^i) = \sum_{i=1}^{n} M^i_{mot}(\omega, U^i)$.

The extended analysis of dynamic characteristics of asynchronous drive is presented in the following papers [1, 3, 6].

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Electropulse technology of briquetting shavings and others scrap of ferrous metals

One of actual problems is rational use of a lightweight metal scrap that is important for their recycling, preservation the fond of metal and uses as cheap charge [1–3]. Them concern a metal shavings, sheet crop, flash, splashing and others. These are an industrial waste which is important to use more full because their repeated recycling to provide the minimum accumulation of impurity. Other perspective source of a lightweight metal waste — the mixed scrap, including en from of a solid domestic wastes. The concept of separate gathering and recycling of the waste, accepted in the developed countries, already at the first stage assumes full recycling metal waste [4]. Russia the next years will join this program, in particular in Saint Petersburg is to utilize by 2014 50% of a waste (it will be in this time thrown out 500 thousand ton ferrous and 260 thousand ton nonferrous metals) [5]. Waste can become a source of the cheap metallurgical raw materials, bat it contain a complex mixed scrap. The offered way of its recycling includes crushing (crushing degree should be above, than on existing the installations intended for recycling of cars) and separation. Magnetic steels can be taken by means of an electromagnet, and stainless steel and nonferrous metals — with the magnetopals separator [6]. In the course of recycling the significant amount of the crushed scrap ferrous and the nonferrous metals which briquetting on existing a briquette–press is impossible is formed. Complexity of processing of a lightweight metal waste is connected with their low bulk density and absence of effective technology of loading at transport and in