Research of the electrical complex of a conveyor with two wire drums

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Abstract. The electrical equipment and control system of the conveyor electric drive are considered. The functional and structural diagrams were drawn up. The analysis of the operation of one- and two-drum electric drives is carried out. Structural diagrams of the mechanical part of the conveyor were obtained. A mathematical description was compiled and modeling of the investigated electric drive was carried out. The structure and model of the elastic link are compiled taking into account the friction forces. The use of a smoothing filter in the speed reference circuit makes it possible to eliminate fluctuations in the system from the reference signal. A mathematical model of the electrical complex has been compiled and its modeling has been carried out. The results obtained confirm the effectiveness of the application of the corrective coupling based on the elastic moment signal.

1. Introduction
There are a large number of options for constructing electrical conveyor complexes (ECC) in the case when two electric drives are connected through an elastic link (conveyor belt) [1-5]. In such systems, asynchronous motors with a wound rotor are widely used, which makes it possible to balance the loads between electric drives. The use of a scheme with a rotary stator [6] makes it possible to control the magnitude of the elastic moment.

2. Problem definition
There is a large number of options for constructing an ECC in the case when two electric drives are connected through an elastic link (conveyor belt) [95,98,103,107,109]. In such systems asynchronous motors with a wound rotor are widely used, what makes it possible to balance the loads between electric drives. The use of a rotary stator circuit [107] makes it possible to control the magnitude of the elastic moment. A block diagram of a two-mass system is known (108). Taking into account the use of electric drives on the first and second mass (drum), the ECC can be represented as a diagram.
Figure 1. Block diagram of an ECC with two drive motors.

It is known that in regulating speed of the AM by changing the voltage, the transfer function of the AM can be represented in the form, with known assumptions:

$$W_{AD}(p) = \frac{\Delta M_{g}(p)}{\Delta u_1} = \frac{K}{(T_1p+1)(T_0p+1)}$$  \hspace{1cm} (1)

$T_1$ - the time constant, which is determined by the aperiodic component of the moment, is the time constant, which determines the attenuation of the periodic component. *$K$* – damping factor.

On figure 1

$$W_{AD}(P) = W_1(P) = W_2(P)$$  \hspace{1cm} (2)

The transfer function characterizing the electromechanical part can be represented by aperiodic links.

$$W_3(p) = \frac{\Delta u_1(p)}{\Delta M_{z2}(p)} = \frac{K_{M1}}{T_{M1}p+1} \hspace{1cm} W_4(p) = \frac{\Delta n_2}{\Delta M_{z2}(p)} = \frac{K_{M2}}{T_{M2}p+1}$$

On figure 1 the elastic link is represented by the transfer function.

$$W_5(P) = \frac{\Delta M_{g}(P)}{\Delta n(P)} = \frac{C}{P}$$

Where $C$ – is stiffness coefficient.

Based on the structural diagram (Fig. 1), you can draw up a system of equations.

$$n_1(P) = W_3(P)[\Delta u(P).W_1(P) - W_5(P)[n_1(P) - n_2(P) - M_{C4}(P)]]$$
$$n_2(P) = W_4(P)[\Delta u(P).W_2(P) + W_5(P)[n_1(P) - n_2(P) - M_{C2}(P)]]$$
$$M_{gnp}(P) = W_5(P)[n_1(P) - n_2(P)]$$  \hspace{1cm} (3)
The system of equations (2.16) makes it possible to obtain functions in terms of decreasing $W_g(P)$ and perturbing $W_B(P)$ influences.

$$W_g(P) = \frac{M_{gup}(P)}{\Delta u(P)} = W_5(P) \frac{W_1(P)W_3(P) - W_2(P)W_4(P)}{1 + [W_3(P) + W_4]W_5(P)}$$ (4)

$$W_B(P) = \frac{M_{gup}(P)}{\Delta M_{c1}} = \frac{W_3(P)W_5(P)}{1 + [W_3(P) + W_4]W_5(P)}$$ (5)

Analysis of expressions (4 and 5) shows that under conditions (3) and (6)

$$W_3(P) = W_4(P)$$ (6)

The transfer function $W_y(P)$ becomes equal to zero;

Denominators $W_y(P)$ and $W_B(P)$ are equal to each other.

3. Theory

The main mode of operation of the ECC under consideration is the development of various parametric disturbances (change $K_{M1}, K_{M2}, T_{M1}, T_{M2}$).

Let us estimate the sensitivity of the transfer function (5) to parametric perturbations

$$W_B(P) = \frac{K_3C(T_3P + 1)}{P(T_3P + 1)(T_4P + 1)[C[K_3(T_4P + 1) + T_4(T_3P + 1)]}$$ (7)

The sensitivity function of the transfer function $W(P)$ to parameter $a$ is determined by the expression:

$$\int_a^W = \frac{dW(P)}{da} \cdot \frac{a}{W(P)}$$ (8)

Based on formulas (7) and (8) can be prepared

$$\int_{T_3}^{W_B(P)} = \frac{P(T_3P + 1)}{K_3}$$

$$\int_{C}^{W_B(P)} = \frac{P(T_3P + 1)(T_4P + 1) + C[K_3(T_4P + 1) + T_4(T_3P + 1)]}{P(T_3P + 1)(T_4P + 1) + C[2K_3(T_4P + 1) + T_4(T_3P + 1)]}$$

$$\int_{K_3}^{W_B(P)} = \frac{(T_P + 1)[P(T_4P + 1) + K_4C]}{P(T_3P + 1)(T_4P + 1) + C[2K_3(T_4P + 1) + T_4(T_3P + 1)]}$$

$$\int_{T_4}^{W_B(P)} = \frac{K_4T_4(T_3P + 1)}{K_3(T_4P + 1)[P(T_3P + 1)(T_4P + 1) + C[2K_3(T_4P + 1) + T_4(T_3P + 1)]]}$$

Let us estimate the influence of random signal $\Delta M_{c1}$ on the value of the elastic moment. For $W_B(P)$ we can use the expression.
\[ I_3 = \frac{C_2^2 d_o d_3 + (C_1 - C_2) d_o d_3 + C_0^2 d_2 d_3}{2d_0 d_3 (d_1 d_2 - d_0 d_3)} \]  

(9)

Where \( C_0 = \kappa_3 C \), \( C_1 = \kappa_3 CT_4 \), \( C_2 = 0 \), \( d_o = C(K_3 + K_4) \), \( d_o = C(K_3 + K_4) \), \( d_1 = cK_3 T_4 + cK_4 T_3 + 1 \), \( d_2 = T_3 + T_4 \)

After substitution and transformation, formula (9) takes the form

\[ I_3 = \frac{K_3^2 c [T_4^2 c(K_4 + K_3) + (T_3 + T_4)]}{2(K_3 + K_4) [(C K_3 T_4 + C K_4 T_3 + 1)(T_3 + T_4) - c(K_3 + K_4) T_3 T_4]} \]

For \( C, K_3, T_3 \) function \( T_3 \) changes monotonically (there is no extremum)

For \( T_4 \) the extremum condition is determined by the expression

\[ 2T_4 T_3^2 K_4 (K_3 + K_4) + T_3^2 K_4 - 2T_3 T_4 K_3 - T_3^2 K_3 = 0 \]  

(10)

Under the condition \( T_3 = T_4 \) and \( K_3 = K_4 \), expression (10) takes the form

\[ 2T_3 K_3 = 1 \]

In fig. 2 and 3 showing 3D graphs of functions \( F(T_3, K_3, \alpha) \) and \( F(T_3, K_3, \beta) \)

Where \( \alpha = \frac{K_3}{K_4} \); \( \beta = \frac{T_3}{T_4} \)

The mechanical part of the conveyor is a system with distribution masses and elasticity in the working body. The publications [95,101] consider various options for representing such systems. A detailed description leads to the appearance of a structure of hyperbolic functions, which significantly complicate the analysis and synthesis of the system in this version. In (95) it is noted that it is more convenient to study the system if the conveyor belt is represented in the form of concentrated masses equal to six. The main natural vibration frequencies correspond to the distribution masses system. At the same time, if the aperiodic process in an elastic link (tape) is provided with the help of an adjustable electric drive, the System can be represented in a form convenient for analysis and synthesis. In this case, for a single-engine (single-drum) electric drive, the mechanical part is described by the system of equations.

\[
\begin{align*}
J_1 PW_1 &= M - My_1 + My_2 - K_1 W_1 \\
J_2 PW_2 &= My_1 - My_2 + Mc - K_2 W_2 \\
PM_{y1} &= C_1 (W_1 - W_2) \\
PM_{y2} &= C_2 (W_2 - W_1)
\end{align*}
\]

(11)

Where \( J_1 \) is the total reduced moment of the drive drum, \( J_2 \) the moment of inertia of the mechanical part of the conveyor with a load, \( W_1 \) the angular speed of the motor, \( W_2 \) the reduced angular speed of the belt, \( M \) is the motor moment, \( Mc \) is the resistance moment, \( My_1 \) is the elastic moment forces on the incoming branch, \( My_2 \) is the moment of elastic forces on the outgoing
branch, $C_1$ the stiffness coefficient between the first and second masses, $C_2$ the stiffness coefficient between the second first masses, $M_{ynp}$ is the elastic load moment.

$$C_1 = \frac{E_1}{l_1} \rho^2 \qquad ; \qquad C_2 = \frac{E_2}{l_2} \rho^2$$

Where $E_1$ is the modulus of elasticity, $\rho$ is the target radius.

$L_1$ and $L_2$ depend on the location of the center of mass of the load on the belt (Figure 2)

$L_1$ – the distance between $M_1$ and $M_2$

$$L_2 = 2L - L_1$$

In accordance with Figure 2, we can draw up a block diagram.

Figure 2. Scheme for $L_1$ and $L_2$.

Figure 3. A block diagram of the mechanical part of a single-drum conveyor drive.
Consider the mechanical part of a two-motor (double-drum) conveyor electric drive.

Assumptions similar to the previous scheme are accepted. In this case, the dynamics of the mechanical part of the conveyor can be represented by a system of equations:

\[
\begin{align*}
J_1 PW_1 &= M_1 - My_1 + M_y3 - K_1 W_1 \\
J_2 PW_2 &= M_y1 - My_2 - M_c - K_2 W_2 \\
J_3 PW_3 &= M_3 + My_2 - M_y3 - K_3 W_3 \\
PM_y1 &= C_1(W_1 - W_2) \\
PM_y2 &= C_2(W_2 - W_3) \\
PM_y3 &= C_3(W_3 - W_1)
\end{align*}
\] (13)

Figure 4 shows a diagram that explains the distribution of elastic moments.

![Diagram of the distribution of moments and elasticities.](image)

**Figure 4.** A diagram of the distribution of moments and elasticities.

For this situation:

\[
C_1 = \frac{E_1}{l_1} \rho^2 ; \quad C_2 = \frac{E_1}{l_2} \rho^2 ; \quad C_3 = \frac{E_1}{L} \rho^2
\] (14)

In accordance with the system of equations (14), a structural diagram of the mechanical part of the two-motor electric drive of the conveyor has been drawn up (Figure 5).
4. Experiment results
Simulation of the mechanical part of the conveyor shows that, regardless of the load, weakly damped oscillations are present in the signals $W$ and $M_{\text{cnt}}$.

The mechanical part of the conveyor with two driven drums and annular elasticity was described and simulated. With the help of an adjustable electric drive, the dynamic performance of the electrical complex can be improved. We believe that $M_1$ and $M_3$ (Figure 5) are created by adjustable electric drives, built according to the structure of subordinate regulation with torque and speed loops tuned to the technical optimum. Based on the analysis carried out earlier, the effectiveness of the use of the $M_{\text{upr}}$ control loop was shown. Taking this into account, the structural diagram of the electrical complex of the conveyor takes the form (Figure 6.)
Figure 6. Block diagram of an electrical complex with a control loop \( M_{\text{upr}} \).

Figure (6) indicates \( P_{W1}(p), P_{W3}(p), P_{M_{\text{upr}}}(p) \) contour regulators of the corresponding coordinates, \( W_{f}(p) \), a filter in the speed reference circuit, \( W_{KM}(p) \) - closed control loops \( M_{1} \), and \( M_{2} \).

The resulting system was simulated. Figure (6) shows the graphs for ECC with closed control loops \( w_{1}, w_{3} \) without control loop \( M_{\text{cnt}}(p) \). At the moment of time \( t = 20c \), the load \( M_{s} \) acts, at \( t = 40c \), the task and is received and \( M_{\text{cnt}}(p) \).

It can be seen that closed control loops make it possible to eliminate oscillation in the ECC. At the same time, at start-up, there is a large overshoot of the M control coordinate. In addition, the action \( M_{C} \) leads to the appearance of \( M_{\text{cnt}} \).
Figure 7. Transient processes in a system with closed speed control loops $\omega_1$ and $\omega_3$ without a control loop $M_{cnt}$.

It can be seen that closed control loops $\omega_1$ and $\omega_3$ make it possible to eliminate oscillation in the ECC. At the same time, there is a large coordinate overshoot at start-up. In addition, the action $M_c$ results in the appearance $M_{cnt}$.

Figure 8 shows the processes when the circuit is on (Mupr). It can be seen that the overshoot has decreased by almost 2 times and the influence $M_c$ on $M_{cnt}$. 
Figure 8. Transient processes in the system with the included elastic moment regulator, there is no filter $W_\phi(p)$.

Figure 9 shows the effect of the filter in the reference chain $\nu_{3\omega}$, ($T_\phi = 2.5c$).

Figure 9. Transient processes with the included filter $W_\phi(p)$. 
5. Conclusion
Measurement of the controlled coordinates allows us to note that in the speed loop in the starting mode, the oscillation is completely eliminated, the overshoot (MUPR) is significantly reduced.

The study of the two-mass system and the results of the analysis of the ECC with ring elasticity shows good agreement on the results of the technical solutions used to improve the quality of the ECC.

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