Modelling and control system of multi motor conveyor

M S Kovalchuk and S V Baburin
Saint-Petersburg Mining University, 2, 21 Line, Saint-Petersburg, 199106, Russia
E-mail: cheremushkina-ms@yandex.ru

Abstract. The paper deals with the actual problem of developing the mathematical model of electromechanical system: conveyor – multimotor electric drive with a frequency converter, with the implementation in Simulink/MatLab, which allows one to perform studies of conveyor operation modes, taking into account the specifics of the mechanism with different electric drives control algorithms. The authors designed the mathematical models of the conveyor and its control system that provides increased uniformity of load distribution between drive motors and restriction of dynamic loads on the belt (over-regulation until 15%).

1. Introduction
The main trend in the development of transport systems is the conversion to full cycle conveyor transport. A conveyor line is a transport system consisting of multiple conveyors. This system creates solid traffic, and stopping one of the conveyors in the transport system leads to stop of the entire plant for the time of failure liquidation. Therefore, the reduction in the reliability of one of the conveyors in the transport system may reduce the throughput of the entire process.

The paper deals with the actual problem of developing the control algorithm that meets the technical requirements for the mine belt conveyors, and enables energy and resource savings taking into account a random sort of traffic. The most effective method of solution of these tasks is the construction of control systems with the use of variable speed drives for asynchronous motors.

2. Technical requirements and the model of conveyor
The value of conveyor belts tension is determined by the dynamic process occurring in belt conveyors. Therefore, an important point in the research related to increasing of durability of the conveyor belts is the study of dynamic processes occurring during the work of belt conveyor and analysis of the main devices of belt conveyors that control the parameters of their work, the speed and tension of the belts.

Electric drives of belt conveyors have the following requirements [1]:
- to provide the tractive effort of a conveyor belt to meet the prescribed requirements for starting, moving and stopping regimes of the belt in all modes of conveyor operation;
- coordinating the work of the drives of multi-drive belt conveyor in order to provide the rational distribution of load between them, eliminating the possibility of slippage of the belt on all or several drive stations, reducing the tension of the belt along the entire length of the conveyor;
- providing speed control of the conveyor belt and the ability to change direction in order to adjust the performance of the conveyor.

Development of a conveyor mathematical model was carried out in a number of other works [2]. For refined simulation of the conveyor, one should consider that during the starting and stopping of the conveyor, dynamic forces occur caused by acceleration of the rotating masses of the drive
mechanism, drums and masses of the belt and minerals. The change in dynamic forces has a wave nature, which is particularly important in long conveyor belts, in which the displacement of the stresses along the belt at the top and the bottom of the traction tension continues beginning from several seconds up to several tens of seconds (depending on the length of the conveyor and a soft start). As a result, the belt is not moving uniformly along the entire length, but the masses start to move as the wave of tensions moves.

In the first instance of time, most of the starting torque developed by the motor, is used to accelerate the drive mechanism mass, so as masses of relatively rigid drive complex move quickly, and the moment of inertia does not change. The belt and its associated mass are set in motion, increasing their ratio in the total accelerated mass, as well as increasing the torque transmitted through the drum to the belt. As a result, the strength of the belt increases gradually during acceleration of the conveyor.

To ensure soft start (limitation of pulls in the belt at start-up), it is necessary to determinate such tension loop of the belt which would provide start-up and braking of the conveyor without the slipping of the belt on drive drums and stability loss of the belt.

The estimated effort of the tension device, thus, is associated with extreme dynamic tension of the belt and with the conveyor drive characteristics. If the drive provides soft start of the conveyor, the tension device can be reduced accordingly, and can be applied to the belt with less longitudinal strength. The transient analysis also includes determining the time of start-up and braking of the conveyor. Due to the fact that direct measurement of the dynamic tension of the belt causes considerable trouble, time control of starting and braking is often the only factor allowing one to assess the compliance of actual and designed characteristics of the drive.

Analysis of the transient modes based on the analysis of wave processes occurring in the belt at start-up and braking of the conveyor. The most important parameter of the wave process is the speed of propagation of longitudinal elastic waves.

The main difficulty in calculating the velocity of wave propagation in the conveyor belt is associated with the following factors [3]:
1) longitudinal rigidity of the conveyor belt is determined not only by longitudinal elastic deformations, but also by the shape and size of the sag between the carrying rollers and, hence, nonlinearly depends on the tension of the belt;
2) the belt has a considerable internal friction, it is the flexible object and its mechanical properties depend on a loading rate, i.e. the longitudinal stiffness of the belt during the propagation of elastic waves is also determined by the abruptness of the front wave; the wave velocity in general depends not only on elastic, but also viscous characteristics of the belt, and their values are usually known only approximately;
3) a part of the energy of the direct wave launcher in the moving fixed belt is used to overcome the friction forces in roller carriages (if these forces before the movement are not equal in magnitude and direction of the friction forces when moving at a steady speed of the belt); therefore, the speed of propagation of the direct wave is reduced and its value is determined by the pre-tension diagram of the circuit belt and a constantly changing acceleration on the wave front.

One should be aware that mining traffics are random in nature and the starting mode in a plant environment occurs with the uncertainty of the static moment. Thus, the action of excessive efforts developed by the drive can cause slippage of the belt on the drum and significant dynamic forces.

As is known [4], the slipping mode of the conveyor belt on the surface of the drive drum satisfies the following conditions:

\[
\frac{M_H}{M_{CB}} = e^{\mu \alpha},
\]

where \( \mu \) - coefficient of friction; \( \alpha \) - angle of the girth.

The expression, written as a relation:
is a condition of the operation mode of the conveyor without slipping of the belt. Substituting the values \( M_{H}, M_{CB} \) into this expression, one can get:

\[
\frac{M_{H}}{M_{CB}} \leq e^{\mu \alpha}
\]

Taking into account given assumptions and considering that both branches of the conveyor are symmetric, i.e., performing equalities \( C_{H} = C_{C} = \frac{C}{2}; \  n_{H} = n_{C} = n; \  M_{RC} = M_{fH} = M_{fH} \), one can write the previous relation in the form:

\[
\left\{ \int_{0}^{t} (\omega_{1} - \omega_{2}) d\epsilon + nC(\omega_{1} - \omega_{2}) \right\} \leq 2M_{f} \frac{\alpha^{\mu}a - 1}{\alpha^{\mu}a + 1}
\]

In the left part of this relation, there is the expression defining the magnitude of resulting moment \( M_{12} \) caused by the forces of conveyor belt deformation, and the right is a constant defined by initial conditions \( M_{H} \) and parameters \( \mu \) and \( \alpha \) of the drum conveyor drive. Considering this [5], the block diagram of the object, allowing one to consider the possibility of a slipping mode, takes the form shown in Fig. 1.

![Figure 1. Block diagram of conveyor with respect to slipping mode](image)

The model of the conveyor was designed in the program Matlab/Simulink (Fig. 2). It can help to analyze the modes of conveyors’ start-up in a predetermined order with a rated torque up to the rated speed, deceleration, work of conveyors with a predetermined load and to obtain dependences (recorders w-1234, I_1234, Tm_12) determining the workload of individual conveyors in the system and showing the change of the conveyor speed depending on the load [6].
In Fig. 2, Unit 1 simulates the variation of the load on the conveyor. The input signals 'Tm' are from the block 'Loading' (Figure 1), taking into account the random type of traffic and a constant value of load 'Constant'. Unit 2 determines the response of the conveyor to input signal U (the control action from the control system of the continuous transport system depending on the conveyors load). The output of the model ‘Tm1’ is the load supplied to the next belt conveyor (Figure 1, blocks ‘conv1-conv4’); 'w' (Figure 2) is the speed of the movement of the belt of the conveyor, which is displayed on the monitor (Figure 1, monitor w1234); Is - stator current that determines the load level of the conveyor (Figure1, monitor I-1234).

3. The control system

Operating conditions of the electric drive of the conveyor has a number of specific features that impose additional requirements on the choice of the control algorithm: ensure soft start with restriction of transient accelerations; necessitate the creation of starting torque several times higher than nominal; minimize the time of starting and braking with restriction of the dynamic tension of the belt and no slipping of the belt [7].

The conveyor as the object of control is characterized by a certain variety of input and output parameters. The entrance control system receives certain input variables that are formed using sensors. System output using the specified control algorithm is formed by a set of output variables, controlling variables. The values of output variables are used at the input of the control object based on the values of input parameters of the control object, modify the behavior of the object in a given direction.

The automatic drive control in this case is rationally divided into the subsystem of reference signals formation of the movement (i.e., the formation of acceleration and deceleration characteristics) and controllers of individual drives that form the local control algorithms and supporting motor parameters (flux linkage and stator current) at the required level.

According to the above-mentioned facts, the control unit should be allocated to the overall system, the input of which is speed of conveyor movement and restriction of its derivative at the time of start-up and braking, and outputs are assignments for local systems (second component) flow and torque of the motor. Moments of motors of the conveyor multi-engine electric drive should be forced to align.

To implement such system, the DTC–control system (Direct Torque Control) was chosen, which was electrically synthesized with the use of methods taking into account the nonlinear character of the control object and the discontinuity nature of the processes in the power converter, which provides [8]:

• simplification of the synthesis algorithm because of the lack of the necessity of providing signals to compensate for internal cross-feedback of the object;
• invariance to external and parametric perturbations, allowing one to solve the problem of identifying the time constant of the rotor and the accuracy of the angular position of reference vector $\Psi_r$;  
• merge objectives of organization of the automatic control system for the frequency controlled motor and PWM control of the autonomous inverter.

The mathematical model of a DTC system was designed in the program Simulink and is shown in Fig. 3. The inputs to the system are tasks of flux and torque of the motor, and the power supply voltage of the drive, outputs are torque and speed of the motor. The block modeling of the control system includes a block "observer coordinates", calculates the torque and motor flux. In Fig. 2, the block "control system" and blocks "switch" are the implementation of the algorithm of voltage vector selection and the algorithm of power switches actuation in the inverter. The block "control system" is executed in the form of S-function (Simulink application written in the programming language "C"). For selection of the voltage vector, the corresponding program was also written.

The system of conveyor electric drive control can be divided into the following modes [3]:
1. Acceleration of the conveyor.
2. Steady-state mode.
3. Braking of the conveyor.

![Figure 3. Motor with DTC system](image)

So to start the conveyor, one should ensure the following conditions [9]:
- the main drive starts and accelerates at a low speed (10% of nominal), and pauses at this speed;  
- the intermediate drive provides torque based on load information of tension from the belt sensor, i.e. start taking into account the inertia of the belt;  
- the moving conveyor belt accelerates through the curve of acceleration to operating speed.

Braking the main drive linearly decelerates the conveyor until it reaches the speed equal to 5% of nominal. At this speed, one should apply the brakes for the final stop of the conveyor.

The work of the multi-motor electric drive of the belt conveyor, as a rule, takes place under
conditions of uneven loading on the motors, so it requires the redistribution of the load between them.

The created model of the multimotor electric drive in Simulink Matlab allows one to evaluate the uneven distribution of the load between motors.

Figure 4 presents characteristics of motor current and torque when load is applied. The load is set by adjustment of the current of load motors. The comparison of the simulation results showed that the mismatch between the calculated and experimental curves is not more than 10%.

With the presented mathematical model, the system of direct torque control (DTC) for the multiengine asynchronous electric drive of the conveyor was adjusted.

![Figure 4. Characteristics of torque during start-up, load-off and load-on (blue – existing system of drive control of conveyors; black - direct torque control (DTC)).](image)

Figure 4 presents the curves of moment change during start-up under the rated load, load-off and load-on, illustrating the decrease in the dynamic moment (15-20)% compared to the existing control systems for conveyor drives.

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4. Conclusion

Improving energy and resource savings of the conveyor transport requires the installation of the regulated asynchronous electric drive with semiconductor frequency converters and control of operating modes of the cross conveyors line in consideration with the technological requirements and a random type of traffic.

The mathematical model of the electromechanical system implemented in Simulink Matlab allows one to perform research of the conveyor operating modes taking into account the specifics of the mechanism operation with different control algorithms of electric drives.

The authors demonstrated the expediency of applying the DTC system of the induction motor together with the algorithm of reference signals adjustment, providing increased uniformity of load distribution between drive motors and elimination of belt dynamic loads (over-regulation until 15%).

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