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The control method of ropes slip of a mine winder with friction pulley

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Abstract. The reasons for the development of an emergency mode of ropes slip along the friction pulley are considered. The process of power conversion is described and a system of equations for the movement of vehicles and the electrical values of the drive is composed. A joint simulation of mechanical and electrical values in the electromechanical complex is performed.

1. Introduction

Cage and skip hoistings are the main technological units that provide the operation of underground mining enterprises. Safety and productivity of the enterprise depend on reliable and trouble-free operation of lifting equipment.

Parts and units of mine winders in the process of work are subjected to significant loads, the action of which leads to gradual wear and failure of the mechanism for one reason or another. Access to rapidly wearing parts and parts of the fire alarm system by the personnel is limited, which prevents the continuous assessment of their condition. For this reason, the faults and accidents are not detected in a timely manner, and their nature is not often defined correctly, which greatly increases the production losses. In this regard, timely and accurate determination of the location and nature of damage is an important task for production [1].

2. Problem description

Skip hoisting with a pulley friction includes a complex set of components and units [2,3]:

- the base part of the hoist (figure 1) (friction pulley, deflector pulleys, braking devices, gearbox, mine hoist control unit (HCU));
- hoist vessels (skips) with pull-type devices and ropes;
- loading devices (metering devices), mine shaft with guides, dump tracks;
- electric DC twin-motor drive with a control circuit.

During the technological shift, the whole complex of mine hoist is monitored from the control panel by the skip-hoist operator. In addition, circuits and devices are used that control individual components or emergency situations of the winder.

The emergency control is usually carried out by various kinds of sensors: re-hoisting the 1st and 2nd positions of the skip, the weight of the load in the skip, brake pad wear, speeding, etc. The total number of sensors on the skip hoist is approximately twenty.

The emergency slip of the ropes along the traction sheave is typical for winders with a friction pulley. The cause of its occurrence is local reduction of the friction coefficient of the pulley lining and dynamic phenomena in the rope in the friction zone of the lining – rope pair.

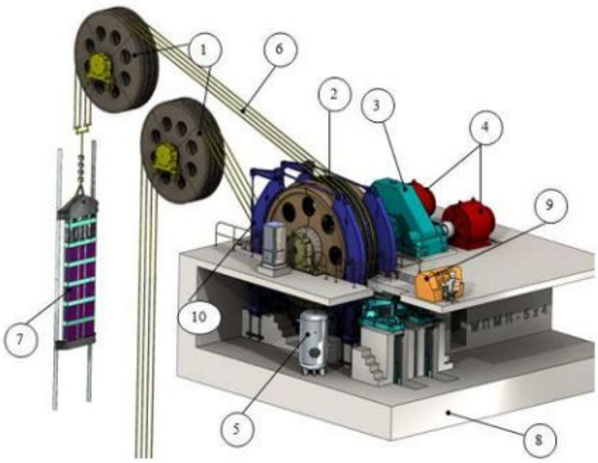

Figure 1. General view of a mine winder:
1 – deflector pulleys,
2 – friction pulley,
3 – gearbox,
4 – engines,
5 – air intake,
6 – rope,
7 – counterweight,
8 – foundation,
9 – control panel,
10 – braking device with two crank levers.

The safety of the hoisting and the reliability of the winder operation largely depend on the design and lining material of the driving pulleys. The lining provides the necessary adhesion of the hoisting ropes with the traction sheave, the long (2-3 years) hoisting performance at a given pressure and temperature without ropes slipping, load balancing. Currently, PP-45 plastic compound, which is a polyvinyl chloride plasticized with dioctylphthalate, is mainly used as the lining of the drive and deflector pulleys of winders [4]. This lining allows a design friction coefficient of 0.25 and a specific pressure of 2 MPa to be paired with strand ropes. The surface of the pulleys of domestic multi-rope winders is lined with bars from commercially available plastic PP-45. Lining pads are pressed against the sheath of the pulley by fastening wedges.

The lining block section is unified. The lining of cable-guide pulleys is pierced with a special device with a difference in the diameter of the grooves for the ropes exceeding 0.5 mm.

The main malfunctions of the traction sheaves are mainly related to the wear of the lining and its fastening. The presence of a large number of holes for bolts for attaching the lining weakens the shell and causes cracking. Different rope tension causes uneven wear of the lining. The disadvantage of the lining is that when it is heated (up to 100°C) it softens and the coefficient of friction decreases. At low temperatures it loses its frictional properties.

During the rope sliding 20-30 cm along the lining, its upper layer begins to melt. Thus, even with a minor disturbance of the normal mode, the rope slips along the traction sheave, causing the lining melting and an emergency situation.

To control the ropes slip, the schemes are used that compare the rotational speeds of the traction sheave and deflecting pulleys. Sometimes skip speeds are additionally measured [5]. The schemes involve the use of a significant amount of additional equipment and, due to this fact they are not very reliable. The consequences of emergency situations with ropes slip over the pulley, taking into account the size and mass of the vessels, speed, depth of the shaft, are serious. In this regard, timely and accurate determination of the rope slip is an important task for production. In a production environment for its implementation can be used the method of energy evaluation of the drive performance [1].

3. Results and discussion

To register an emergency according to [1] information on the electrical values of the winder drive can be used. In the case of a DC drive, information is provided on the magnitudes of the current of motor armature circuit, excitation winding current, motor armature voltage and their rotation frequency [1,6]. It is possible and appropriate, based on the results of work [1,6], to use information about the electrical values of the winder drive to determine the emergency situation of rope slip along a traction sheave.

To apply this control method, it is necessary to keep in mind that the work of a skip lift is accompanied by a continuous process of converting one type of energy into another. The electrical

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energy of the source (electrical network) is converted into the energy of rotational motion on the motor shaft and is then used in the mechanism for performing useful work. The amount of energy converted from one form to another, according to the law of its conservation with allowance for losses, must be the same at any time interval. The power values of the various processes are described by the following well-known expressions:

- power of the three-phase AC network:

$$P = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi, \quad W \tag{1}$$

where U is the line voltage, V; I – phase current network, A; $\cos\varphi$ – is the power factor.

- power (electrical) at the DC terminals of the converter and the armature circuit of the driving motor:

$$P = U \cdot I, \quad W \tag{2}$$

where U is the voltage of armature circuit, V; I – current of the armature circuit, A.

- mechanical power on the motor shaft:

$$P = M \cdot \omega, \quad W \tag{3}$$

where M is the mechanical moment of the electric motor, N·m; ω – angular frequency of shaft rotation, s^{-1}.

- total power of moving and rotating parts of the mechanism:

$$P = (F_{ten1} - F_{ten2}) \cdot \upsilon + J \cdot \omega \cdot \varepsilon \tag{4}$$

where F_{nat1}, F_{nat2} are the tension forces of the ropes, N; υ – skips linear speed; ω – frequency of motor shaft rotation; J – reduced moment of inertia; ε – the angular acceleration of the drive.

Any of the emergency situations (including slippage of the rope on the friction pulley) leads to a deviation of the mechanical torque on the shaft of the hoist motors from the normal value for this mode [6]. As a result, the electrical values of the drive of the winder are changed according to the scheme [7]:

$$\downarrow M_T \rightarrow \uparrow n \rightarrow \uparrow E_a \, (E_A = c_E n \Phi) \rightarrow \downarrow I_a \, (I_A = \frac{U - E_A}{R_A}) \tag{5}$$

The design scheme for performing joint modeling of mechanical and electrical values in the electromechanical complex is shown in figure 2.

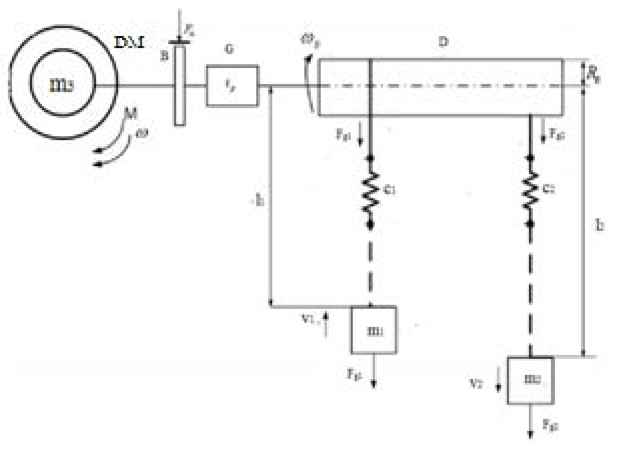

Figure 2. Calculation scheme for the determination of mechanical and electrical values of the winder drive:
DM – drive motor;
B – brake mechanism;
D – drum;
G – gearbox;
m_1, m_2, m_3 – masses of rotating parts, vehicles and ropes reduced to the movement of the ropes;
l_1, l_2 – variable lengths of hoist cables;
F_{g1}, F_{g2}, F_{g1}, F_{g2} – the gravity of the vehicles and the elastic force of the hoisting cables;
c_1, c_2 – rigidity of the hoisting ropes.

The mechanical part of the winder is represented by a three-mass system with elastic connections between the masses. The system of equations links the movement of masses and the electrical quantities of the driving motor (6):

$$\begin{cases} m_1 \cdot x_1^{//} = -F_{y1} - F_{m1} = -c_1(x_1 - x_3) - m_1 g; \\ m_2 \cdot x_2^{//} = F_{y2} + F_{m2} = c_2(x_2 - x_3) - m_2 g; \\ m_3 \cdot x_3^{//} = \beta \cdot L_m(i_a \cdot i_e) - F_{y1} + F_{y2} = \beta \cdot L_m(i_a \cdot i_e) - c_1(x_1 - x_3) + c_2(x_2 - x_3); \\ F_{fr} = -F_{y1} + F_{y2} = -c_1(x_1 - x_3) + c_2(x_2 - x_3) = k(m_1 g + m_2 g); \\ L_a \dfrac{di_a}{dt} + c_e \cdot \beta x_1^{/} \cdot L_m i_e + r_a i_a = U_a; \\ L_e \dfrac{di_e}{dt} + L_m \dfrac{di_a}{dt} + r_e i_e = U_e; \end{cases} \tag{6}$$

where m_1, m_2, m_3 – are the masses of rotating parts, vehicles and ropes reduced to the movement of the ropes;

x_1, x_2, x_3 – movement of reduced masses;

k, F_{fr} – coefficient and force of friction of the rope against the lining;

i_a, i_e – currents of the armature and excitation of the electric motor;

β – the coefficient of reduction of the motor dynamics to the movement of the ropes;

c_e – constructive constant electric motor;

L_a, L_e, L_m – inductance of the armature windings, excitation and mutual inductance;

r_a, r_e – active resistance of the armature windings, excitation;

U_a, U_e – supply voltage of armature and excitation circuits.

Simulation of the skip hoist operation in normal mode and emergency situations of rope slipping along the traction sheave was performed in MATLAB environment. The emergency slippage of the rope was simulated by reducing the value of the rope friction coefficient against the lining in equations (6). The results of modeling the vehicles movement in the shaft and the occurrence of rope slippage are shown in figure 3. As the friction coefficient decreases (rope slippage), a deviation from the normal value recorded by measuring means is recorded on the current diagram of drive armature. The deviation from the current values on the current diagram gives information about the location of the fault and its severity (figure 3).

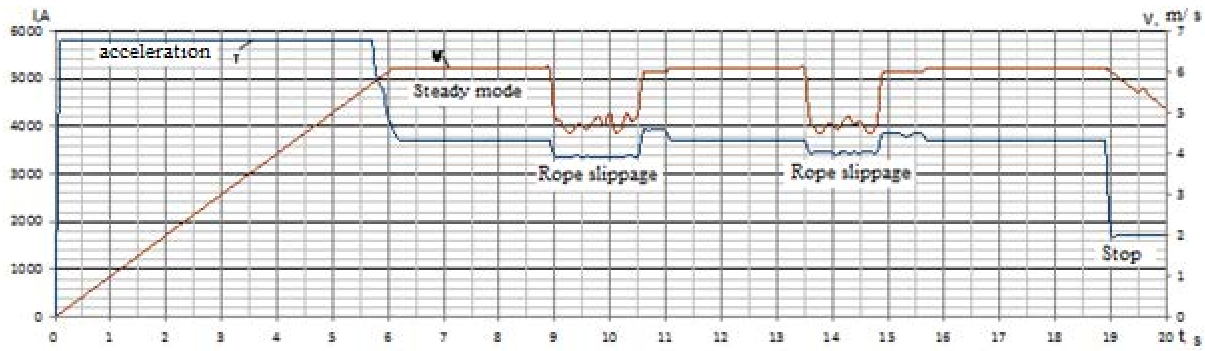

Figure 3. Change in the stator current and skip speed.

When performing additional studies, it is possible to identify most types of faults in the mechanical part of the unit, since the nature of the current deviation from the normal values is related to the type of fault in the mechanical part mentioned above.

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4. Conclusion

Using the electrical parameters control of the winder drive, it is possible to create a special protective device. Such device is capable of recognizing the initial stage of development of the emergency mode by the deviation of monitored currents of electromechanical converters. To control in the "on-line" mode, the protection circuit forms a diagram of current values of the electromechanical converter that is normal for this cycle of hoisting. When a deviation from the normal values appears in the current diagram, the device generates an alarm signal for switching off the drive and stopping the hoisting.

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