SIMULATION TESTINGS OF EMERGENCY BRAKING OF THE MINING SHAFT HOIST

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Abstract: For each mining shaft hoist braking devices shall be provided, which in the event of conveyance overwind the boundary positions, act upon conveyances with braking forces, independently on the brake mounted in a drive. The state, in which the conveyances overwind the boundary positions, is called the shaft hoist emergency braking state. It is the most dangerous emergency event occurring during the shaft hoist operation. Digital simulation of the hoist emergency braking state, carried out on the appropriate model, enables to assess kinematic and dynamic parameters of that process.

Key Words: mining shaft hoist, braking forces, conveyances, Koepe pulley, digital simulation


Słowa kluczowe: górnicze urządzenia wyciągowe, siła hamowania, naczynie wyciągowe, koło pędne systemu Koepe, symulacja cyfrowa
1. Mechanical system of the mine shaft hoist

A shaft hoist constitutes a system of masses, being connected each other, moving in translatory and rotary motion. Conveyances, sections of hoisting and tail ropes move in translatory motion, however Koepe pulley, directional wheels, rotor of the motor, shafts connecting rotor with Koepe pulley, gear wheels in transmission, if drive is equipped in such ones, move in rotary motion. Velocities of masses being in translatory and rotary motion are interdependent. The mechanical scheme of the four rope tower mounted hoist installation is shown in the figure 1.

![Diagram of multi-rope tower mounted hoist installation](image)

*Fig. 1 Scheme of the multi-rope tower mounted hoist installation*

The above mentioned hoist installation may be equipped in the machine driven by two (or one) low speed direct current motors connected through the short rigid shafts with Koepe pulley. On Koepe pulley friction forces between ropes and linings compensate a difference in forces acting in ropes.
on both sides of that pulley. The skip conveyances $m_{wd}$ and $m_r$ are situated close to their end positions in this way that the full conveyance is situated in the headframe. The Koepe pulley is connected by frictional contact with conveyances by means of hoisting and tail ropes situated in line.

It can be seen that we deal with the system consisting of the rotating part composed of bodies of rotation of different moments of inertia connected with short rigid shafts and of the part, moving in translatory motion, composed of conveyances and sections of hoisting and tail ropes having their masses distributed in a continuous way.

To this system, except forces of gravity, motor torques $M_{s1}$ and $M_{s2}$, braking torque from emergency brake $M_h$ may be applied and to conveyances braking forces $F_{hw}$ and $F_{hr}$ from devices, mounted at overwind travels beyond conveyance end positions, may be also applied. The process of emergency braking of the hoist installation evoked by acting braking forces upon conveyances may be divided into two periods:

a) retarded movement of hoist masses until the velocity reaches value of zero with simultaneous increase of dynamic forces;

b) occurring longitudinal oscillations with decay of oscillations of dynamic forces in ropes; these oscillations induce dispersion of part of energy accumulated in the system.

2. Mechanical and mathematical model of the mining shaft hoist

The model of the hoist installation for the analysis of emergency braking state comes down to the presentation of conveyances in their boundary positions. It is one of the most interesting states with regard for occurring dynamic loads in hoist elements. In theoretical works and in simulation tests two kinds of models of hoist installations are generally applied: models with parameters distributed in a continuous way and discrete models.

Building the model of the hoist installation for emergency braking analysis, the following assumptions and simplifications are generally applied:

- ropes, for the range of acting forces, are subjected to the Hooke's law; it is assumed that for equal mechanical properties and loads in ropes, forming the set of hoisting and balance ropes, the ropes constitutes one element;

- lateral rope oscillations are usually neglected;

- elasticity of the other hoist elements, of very low value, is neglected;

- conveyances are treated as stiff elements with masses concentrated in a center of gravity; masses of short sections of ropes above a conveyance in the headframe and under a conveyance in the sump are included to masses of conveyances;
- it is assumed that there is no slip on Koepe pulley;
- with regard to the character of the modelled process, that is very short
time of duration, the change of the length of rope sections
- is neglected.

The mechanical scheme of the hoist and its discrete model of "n" degrees of
freedom has been presented in the figure 2. It was assumed, that braking
forces $F_{br}$ and $F_{bw}$ as functions of path, on which braking is realized, act
upon conveyance masses $m_r$ and $m_w$. The force from the brake $F_{hb(t)}$ and
force $F_{st(t)}$ from the motor torque may act on the mass modelling pulley and
rotors of motors. Applying d'Alembert's principle equations of motion may
be written for each mass of the model. System of motion equations shall
comprise $2n+3$ ordinary differential equations of constant coefficients.
Coordinates of hoist masses have been designated with x and y symbols
with appropriate indexes. It was assumed that total mass of hoisting ropes is
equal to $m_l$ and balance ropes $m_w$.

Fig. 2. Mechanical model of the hoist and its discrete model
System of motion equations for the model according to d’Alembert’s principle is as follows:

\[-m_r \ddot{x}_r - 2k_r \cdot [x_r(t) - x_i(t)] = F_{sr}(s)\]
\[-\frac{m}{n} \ddot{x}_i + 2k_i \cdot [x_r(t) - x_i(t)] - k_j \cdot [x_i(t) - x_j(t)] = 0\]

\[-\frac{m}{n} \ddot{x}_j + k_j \cdot [x_j(t) - x_i(t)] - 2k_j \cdot [x_i(t) - x_j(t)] = 0\]
\[-m_{w_d} \ddot{x}_{w_d} - k_i \cdot [x_{w_d}(t) - x_i(t)] - 2k_i \cdot [y_i(t) - x_{w_d}(t)] = F_{w_d}(s)\]
\[-\frac{m}{n} \ddot{y}_i + 2k_i \cdot [y_i(t) - x_{w_d}(t)] - k_i \cdot [y_i(t) - y_i(t)] = 0\]

\[-\frac{m}{n} \ddot{y}_w + k_w \cdot [y_i(t) - y_{w_r}(t)] = 0\]

3. Example results of simulation of hoist emergency braking

For the model, presented in the previous chapter, the original computer program has been prepared, which enables optional simulation of hoist emergency braking. For one of the mining hoists indispensable parameters for hoist modelling were elaborated and the simulation of conveyance emergency braking were carried out. The runs in time for the following magnitudes, characterizing hoist braking, obtained as a result of braking force acting, are presented in fig. 3:

- conveyance displacement - 3b;
- conveyance velocity - 3c;
- deceleration during braking - 3d;
- force in hoisting ropes - 3e.

For verification of parameters of simulated emergency braking, obtained theoretically, in situ testings on the same hoist have been carried out. The example comparison one of the obtained runs of forces in hoisting ropes is
presented in fig.4; fig. 4a for the theoretical simulation, fig 4b for the carried out testings.

**Fig. 3.** Results of the computer simulation of emergency braking process in movable fender beams, carried out for hoist installation in Bartosz II shaft; velocity of entering into arresting device $v=3 \text{ m/s}$
Fig. 4 Comparison of runs of forces in hoisting ropes (velocity of entering the arresting device $v = 2 \text{ m/s}$)

a - results of simulation, b - results obtained in measurements

4. **Final conclusions**

Comparison of other magnitudes, characterizing braking process proved, that the model elaborated with the simulation program, enables to analyze theoretically the conveyance emergency braking state in a sufficiently precise way.
Bibliography