Choice of energy-saving electric drives in quasi-stationary transport systems

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Abstract. This article presents the structure of a quasi-stationary scheme of conveyor belt transport systems. The ratios of transport losses and characteristics of electrical systems driven by a network and a converter are obtained. The values that affect the losses in the transport system, such as the speed and resistance forces of the conveyor belt and carrier rollers, are determined. Transport losses and characteristics of electrical systems are obtained when powered from the mains and through a converter, inverter operation for active and passive transport systems, network operation with active transport systems, network operation for passive transport systems. Factors are given when choosing energy-saving conveyor drives, a diagram for choosing the most efficient types of drive, taking into account the types of load and intended for various conveyor systems.

1 Introduction

The transport system in technological processes is the subsystem in which most of the losses usually occur. Electric drives in quasi-stationary transport systems (pumping, conveyor and ventilation systems, as well as systems for generating and cooling compressed air) consume up to 70% of electrical energy from the total volume [1-2].

Recently, the priority tasks are the development of energy-efficient and resource-saving technologies in mining and transport installations with a frequency-controlled electric drive, the development of an energy-efficient mode of operation of electric drives of belt conveyors, as well as their control schemes for frequency-controlled electric drives, taking into account the main factors affecting efficiency and the development of a methodology for determining energy efficiency of rock mass transportation processes, new energy and resource saving technologies.

One of the parameters affecting the efficiency of the belt conveyor is the resistance to the movement of the belt. With this in mind, the design resistance was determined depending on the choice of the type of electric drive.

Transport losses P_{Vtr} at transport speed v arise due to friction forces F_{tr} [3]:

$$P_{Vtr} = F_{tr}(v)v \tag{1}$$

Friction forces also depend on the transport speed V.

Friction forces as a whole can be described by the formula [3]:

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$$F_{tr}(v) = F_{tr}|_{v=0} v + \frac{1}{2}\frac{d^2F_{tr}}{dv^2}|_{v=0} \cdot v^2 + \cdots \tag{2}$$

Due to the complexity of transport systems, several types of friction often occur. Since all terms of equation (2) are greater than zero, the friction force usually coincides with the velocity and increases or, in the case of pure sliding friction, Ftr (v) = const. remains constant.

Thus, reducing transport losses has a significant impact on the resulting energy efficiency.

2 Methods

Development of a methodology for determining the energy efficiency of rock mass transportation processes, which will take into account the main influencing factors, establishing control laws for a frequency-controlled electric drive, improving their dynamic modes by developing mathematical models and block diagrams, applying them in mechanisms, creating new methods and technologies for energy and resource saving are now gaining importance.

The subsystems of the general transport system are quasi-stationary circuits, consisting of: a transport system, a mechanical drive, a working machine, a gearbox, a motor, a frequency converter [4-5].

The transport system of the conveyor performs the workflow taking into account the type of cargo from the flow rate J(t) and the height difference H.

The transport system, consisting of a conveyor belt and carrier rollers, transports the load, while the speed of the belt and the resistance forces are determined by the type of load. The working machine transmits the drive torque to the conveyor belt through the drive drum and thus determines the belt tension and belt speed. The gearbox regulates the speed of the drum in accordance with the engine speed. As a drive, asynchronous motors and synchronous motors with permanently magnetic excitations are studied. The frequency converter provides a change in the speed of asynchronous or synchronous motors with a permanent magnet [6-7].

Losses occur in the structure of the belt conveyor and its subsystems. Losses in the converter occur in the power flow from the mains connection to the belt conveyor system, in the motor and in the transmission. The transmission power P_{per} required to drive the drum is calculated by the formula [6]:

$$P_{per} = F_{ob}(J, H)v(J, H). \tag{3}$$

where Ftotal is the total resistance; J is the speed of cargo traffic; H is the lift height.

The mechanical resistance resulting from the conveying process, caused by the friction of the belt and roller and due to the tilt resistance, is part of the total resistance Ftot. The total resistance, as well as the speed of the tape v, directly depend on the size of the load, i.e. on the speed of the cargo flow J and on the height of the lift H.

Drive drum depending on the required frictional properties. can be covered with a rubber friction lining (friction coefficients [8].

Transport losses have a decisive influence on the energy consumption of an installation. Therefore, in active network and converter transport systems, the volume flow V is adjusted according to the transport speed v, where the mass of the load mL remains constant. Transport losses PVtrans (v = var., mL = const) are determined by the formula [9]:

$$P_{Vtr}(v = var., m_l = const) = F_{Reib|_{v=0}}\ v + \frac{dF_{\text{тр}}}{dv}|_{v=0} \cdot v^2 mitv \sim \dot{V}. \tag{4}$$

Thus, the mass of the transported cargo mL depends on the volume flow V, and to determine the effect of the friction force on the transport losses PVtrans (v = const, mL = var.), the Taylor series is used, which determines the friction forces depending on the mass of the cargo [9]:

$$P_{vtr}(v = const, m_l = var.) = (F_{tr|_{m_L=0}} + \frac{dF_{tr}}{dm_l}|_{m_L=0} \cdot v mit m_l \sim \dot{V}. \tag{5}$$

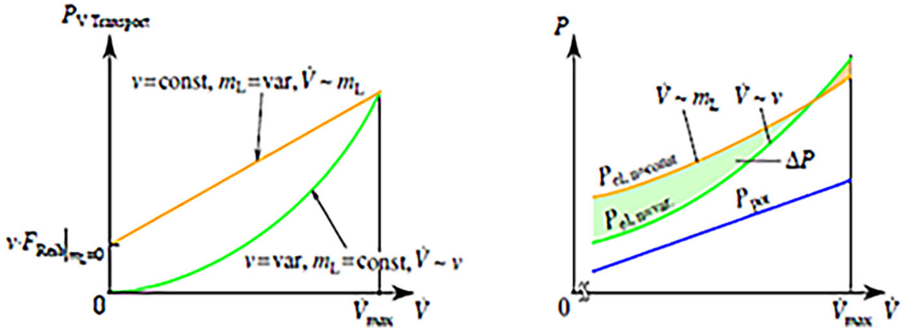
Friction forces increase with an increase in the mass of the load. Losses in (4) depend linearly on the volume flow.

3 Results and discussion

On Figure 1a shows transport losses with volume flow. It can be seen from the graphs that the losses depend linearly on the volume flow. Since all terms in both equations are positive, the volumetric flow rate VMAX decreases at low speed (constant load mass) and is always lower than transport losses than when the load mass decreases (constant speed) [10].

Potential processing power Ppot, which changes the internal energy of the material in addition to transport losses, is an important part in the productivity of the equipment (Figure 1b). Thus, the potential productivity of the process does not depend on the choice between mains and inverter drives.

To save energy, not only the transmission, but the complete transport system must be optimized. This means that the transfer unit is shifted towards the transport process. Instead of torque and speed, it will be possible to use, for example, transported mass flow. Since the set of transport applications includes several physical quantities, determining the appropriate transmission unit requires a certain degree of abstraction. In drive systems, torques and speeds on the output shaft between the drive and the rig are often used by a transfer rig. The display of the flow of time from the load side m over the rotational speed n of the drive gives the characteristics of the installation m-N.



a) transport losses b) performance of the electrical system as a function of volume vs. flow rate flow according to (1) and (2)

Fig 1. Transport losses and characteristics of electrical systems when powered from the network and through the converter.

Reducing transport losses has a significant impact on the resulting energy efficiency. Thus [2]:

1. Sliding friction: it is independent of speed, but depends on downforce and the amount of friction between two bodies.
2. Viscosity of laminar friction: it is proportional to the velocity and depends on the viscosity of the fluid.
3. Turbulent friction: This type of friction increases quadratically with speed and is highly dependent on the roughness and geometry of the guiding fluid.

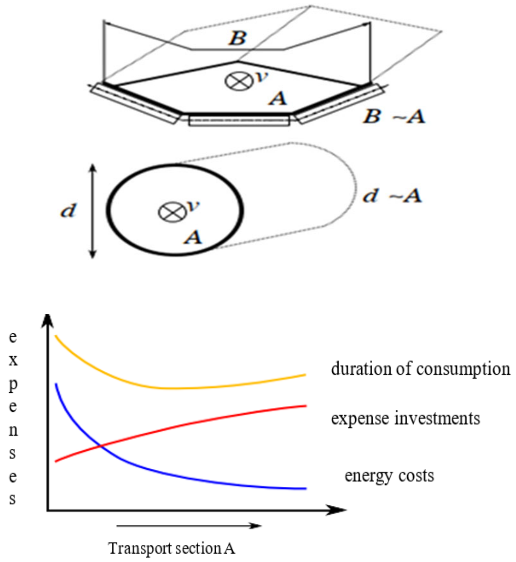
The transport speed v follows from the generalized scheme, in which the size of the process flow is determined by the type of load and the transport cross section A:

$$v = \frac{\dot{V}}{A} \tag{6}$$

Determination of the transport section A is intended for pumping and conveyor installations.

Similarly, as shown in Figure 2 a. in both cases the cross section increases quadratically with the pipe diameter d.

$A = d^2\ b_{zw}$ or with belt width B. An increase in the cross section A results in a reduction in the conveying speed and consequently in conveying losses. On Figure 2b shows energy consumption, costs for a larger transport cross section. However, investment costs are also rising, resulting in a minimum lifetime cost for all transport installations. An increase in section A leads to a decrease in the speed of transportation. Thus, the energy consumption is reduced in the case of a larger cross section during transportation (Figure 2b). At the same time, investment costs are also rising, which is why all transport installations have a minimum service life.



(a) Sketch of the transport section in the pipe system and belt system
(b) Lifetime costs depending on the transport cross-section A

Fig. 2. Influence of the mechanical design of the transport system on energy consumption.

Based on transport losses and potential processing power, electrical system P_{el} for active or passive transport systems with inverter or mains power drives are obtained:

- Inverter operation for active and passive conveying systems: here the conveying speed is determined by the motor speed depending on the flow. The power of the electrical system Pel,n=var in (Figure 2) is obtained from the operating point - dependent efficiency of the working machine ηrm, transmission ηtrans, engine ηmotor and converter ηinv. The performance of the R_{el} installation, n=var in Figure 2 b at maximum flow due to additional losses of the converter and additional losses in the motor (due to harmonics) slightly increases, but decreases with less linear-quadratic flow in (1).
- Network operation with active transport systems: Constant drive speed requires a mechanism to reduce the flow rate. The drive generates additional losses in the partial load range and allows you to adjust the transport speed v, which is applied in (1). The performance of the R_{el} installation, n=const in Figure 2b is at the maximum

flow below the speed control output, but decreases due to the loss in the drive in the partial load range is not so great.

- Network operation for passive transport systems: Reduced flow leads to a constant decrease in the mass of the load mL. Due to the increased transport losses, the performance of the R_{el} installation, n=const, also decreases in Figure 2b, not as much as when the converter is running.

The distinction between constant speed mains drives and inverter variable speed drives allows adaptation to smaller feed flows. Variable speed drives above rated speed provide advantages in fluid handling equipment across plant sizes as well as efficiency due to higher rotation speeds.

The speed regulation of induction motors is associated with additional costs. Correction of the speed and torque characteristics of asynchronous motors with a fixed number of pole pairs is possible with the help of electrical frequency, chain tension or with the help of additional rotor resistors. Transformers or thyristor resistance boxes are used for voltage regulation, and slip control is needed to use rotary auxiliary resistors. These speed control capabilities are often referred to as slip control and the increased slip significantly increases power dissipation.

Speed control with pole-switched induction motors results in lower losses and a larger speed control range than slip control. However, pole-changing induction motors are in principle of lower efficiency than IE2-Standard motors of the same power, and the possible speed control range is basically reduced to two ways of limiting the speed. Thus, the control range for transport equipment is also limited.

Simultaneous control of the supply voltage and frequency, for example via *V/f* control, allows low-slip speed control over a wide control range. Thus, for effective speed control of asynchronous motors, a frequency converter is proposed.

The use of mains or inverter driven drives influences the behavior with time-varying feed flows. Table 1 shows the difference between active and passive vehicles. Passive vehicles receive the supply flow through external installations, while active transport installations provide the supply flow on their own.

Examples of passive bulk handling systems and large conveyor installations, as their feed flow is determined by the above installations. Active transport units, such as pumping units, fans and compressors [4].

Networked active transport units use the mechanical drive (usually bypass or choke fittings) needed to adjust the supply flow V. Reducing the flow to passive grid operated transport units reduces the transported load mass mn - that is, the mass that at a certain time turns into transport systems. Inverter-powered active transport units allow the change of the feed flow with the drive speed n_{mot}, while for passive installations the rotation speed is controlled according to the incoming feed flow.

Table 1. Conveyor flow change on active and passive transport objects.

Active transport entities	Passive transport entities
network operation drive ↑⇒ V ↓ inverter $n_{дв}$ ↓⇒ $V^{\cdot}$ ↓	$V^{\cdot}$ ↓⇒ m_n ↓ $V^{\cdot}$ ↓⇒ n_{dv} ↓

A comparison between mains and inverter drives showed that one of the two options consumes less energy. The average value of these indicators is called the average energy loss ΔP (when the inverter is running). On Figure 3 shows the energy loss ΔP depending on the process power applied to the total power Ppot/Pel, n=const at the maximum flow rate [5].

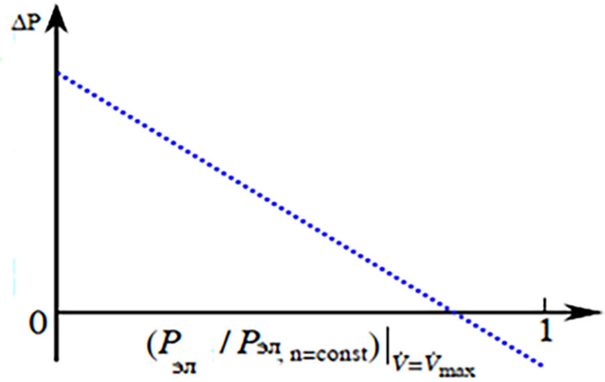


Fig. 3. Potential ΔP savings between converter and mains operation.

As ΔP increases, the power efficiency Ppot decreases and transport losses reduce the energy of inverter driven drives.

Thus, the savings potential of variable speed drives is usually higher. Most of the equipment power used to change the energy of the conveyed material is spent on mains driven drives often more efficiently. However, the final choice of the energy-optimized variant is possible only by including the type of load.

For conveyor systems fixed drives and variable speed drives are advantageous in certain load ranges. The achievable energy savings depend on the distribution of forces in the belt conveyor system and the type of load.

When choosing energy-saving conveyor drives, consider:

- the ratio of resistors with potential characteristics (here, the slope and rolling resistance (Fk and Fk) to the total resistance at maximum flow rate) [11]:

$$\frac{F_{nak}+F_{к}}{total} \tag{7}$$

- ratio of partial load flow to maximum flow:

$$k_{part} = \frac{J_{part}}{J_{мах}} \tag{8}$$

- the ratio of the operating time at partial load to the total operating time:

$$\frac{t_{part}}{t_{o.e.p}} \tag{9}$$

The selection diagram allows you to select the most efficient drive type based on the type of load and is designed for various conveyor systems. According to the diagram, electric drives are compared taking into account all possible types of load of unregulated and adjustable speed [12].

Increasing the energy efficiency of installations leads to lower costs. The benefits of improving energy efficiency are as follows [13]:

- downsizing of electrical and mechanical drive components; (Saving investment costs),
- increased service life of drive components (savings in maintenance costs),
- lower efforts to remove waste heat and low resource consumption, and reduced environmental impact.

Therefore, when designing, it is advisable to take into account the mechanical design, the number of drives and the difference between inverter and mains drives. The system includes selection criteria and a selection diagram. With the help of a selection scheme, the most energy efficient drive type for a particular task is determined at an early stage of development.

4 Conclusion

The selection system is applied to pump and belt conveyor systems and shows high energy savings (up to 40%). To analyze energy saving potentials in these complex transport systems, all subsystems from the working process to the transport system and the electric drive as part of the electrical system connection are used. It is suitable for both pump and conveyor systems, saving both energy and investment costs.

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