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Directions for reducing the energy consumption of mining belt conveyors

The article discusses the issue of energy savings in the operation of mining belt conveyors. Using the concept of energy consumption indicators, the directions for reducing the energy consumption of belt conveyors are presented by applying energy-efficient components, upgrading the drive system, or introducing organizational and technical changes in the conveying process.

Key words: belt conveyors, design, calculations, industrial research, laboratory research, monitoring, operation

1. INTRODUCTION

The main element of the transport system in coal, lignite, and copper mines are belt conveyors, which, as a continuous transport medium, ensure adequate efficiency while maintaining high availability. Despite the best energy consumption indicators among other transport equipment used, the increase in transport routes in mines results in a growing percentage of transport expenses in the overall costs of extracting valuable minerals. Therefore, in connection with this phenomenon and with the constantly increasing costs of electricity, the issues related to the reduction of the energy consumption of belt conveyors are becoming increasingly important.

The basic technical operational parameter that comprehensively describes the unit energy consumption of a belt conveyor drive unit is the energy consumption indicator, defined as the energy value consumed to transport 1 kg of material over a distance of 1 m [1]:

$$w_g = \frac{N}{\dot{M} \cdot L} \left[\frac{\text{W} \cdot \text{s}}{\text{kg} \cdot \text{m}} \right] \quad (1)$$

where:

- \dot{M} – mass flow rate [kg/s],
- N – required drive power [W],
- L – length of the transport path (conveyor) [m].

The energy consumption index is significantly influenced by the profile of the route, the design characteristics of the conveyor, the quality of the components, and the degree of wear, as well as the operating conditions, maintenance, and the use of the conveyor's transport capacity. According to the definition of the index, conveyors with a low load of material will have the highest, i.e. unfavorable values of the energy consumption index, despite the lower power consumption of the drive system, because it relates both to the conveyor's throughput and to the consumption of electrical energy.

After the appropriate transformation of equation (1), taking into account the efficiency of the drive and the fact that its power is the product of the resistance of the conveyor and the speed of the belt, the following expression is obtained:

$$w_E = \frac{N}{M \cdot \eta} \left[\frac{\text{N}}{\text{kg}} \right] \quad (2)$$

where:

- W – total resistance of the conveyor [N],
- M – mass carried on the conveyor [kg],
- η – efficiency of the drive system [-].

According to equation (2), the energy consumption index can be lowered by reducing the resistance of the conveyor – W , increasing the mass carried on

the conveyor – M , and improving the efficiency of the drive system – η .

The following are issues related to reducing the energy consumption of belt conveyors by:

- reducing the resistance of the conveyor by proper selection of operating parameters and the use of appropriate components such as energy-saving belts and rollers with low rotational resistance;
- increasing the degree of utilization of the conveyor’s transport capacity through organizational and technical measures;

- improving the efficiency of the drive system by modernizing motors, clutches, gears, and optimizing drum drive systems.

2. RESISTANCE OF BELT CONVEYORS

The sources of resistance in belt conveyors are friction, gravity, and inertia (Fig. 1). They occur both uniformly distributed along the entire conveyor route W_G , as well as in strictly defined construction locations W_S and on inclined sections of the route W_H .

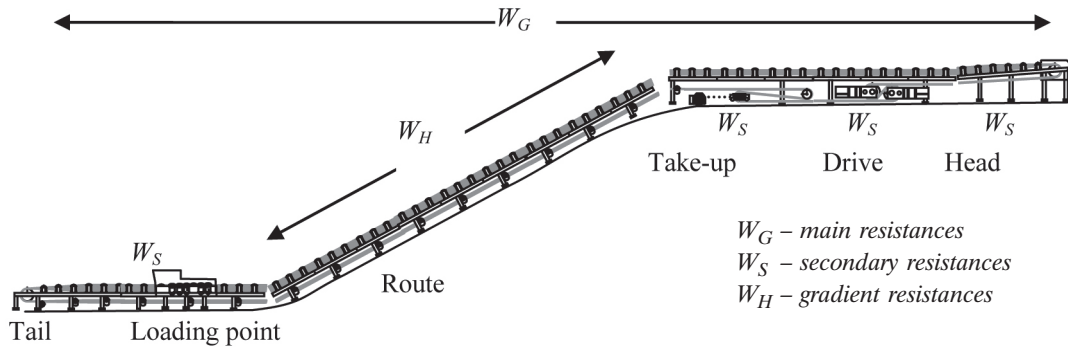


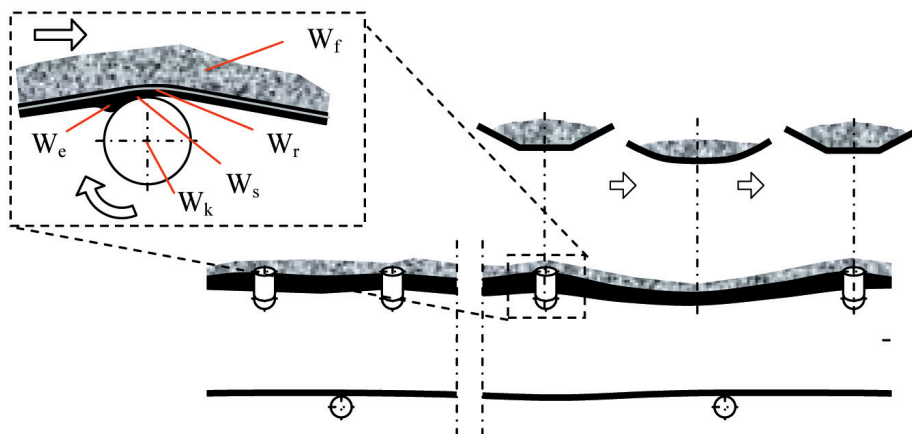
Fig. 1. Examples of areas of occurrence of individual types of resistance in belt conveyors [2]

2.1. Main resistances

The first group of resistances that occurs along the entire conveyor path is called main resistances W_G . The components of these resistances are the following (Fig. 2) [3]:

- rotation of the rollers, dependent on the friction forces in the bearings and their seals – W_k ,

- movement of the belt on the rollers, related to the indentation of the roller into the rubber belt covers – W_e ,
- bending of the belt on the idler sets – W_r ,
- related to the nature and properties of the material being transported – W_f ,
- friction of the belt on the rollers, related to the interaction of the surface of the roller with the rubber belt covers – W_s .



- W_k – resistances rotation of the rollers,
- W_e – resistances movement of the belt on the rollers,
- W_r – resistances bending of the belt on the idler sets,
- W_f – resistances related to the nature and properties of the material being transported,
- W_s – resistances friction of the belt on the rollers.

$$W_G = W_k + W_e + W_r + W_f + W_s$$

Fig. 2. The components of the main resistance of a belt conveyor’s motion

The main resistances are of decisive importance in the selection of a drive system for long conveyors with a slight angle of inclination angle of the path (Fig. 3).

Figure 3 shows an example of the percentage distribution of the individual resistance components in the total movement resistance of a fully loaded horizontal conveyor in an open-cast lignite mine ($L = 1100$ m, $Q = 20,000$ t/h, $v = 5.5$ m/s), determined using the QNK-TT computer program [4]. The structure that constitutes the components of the resistance of a belt conveyor's motion is not constant; it may vary depending on the type of conveyor, its operating parameters, the place of operation, the degree of loading, and the properties of the transported material.

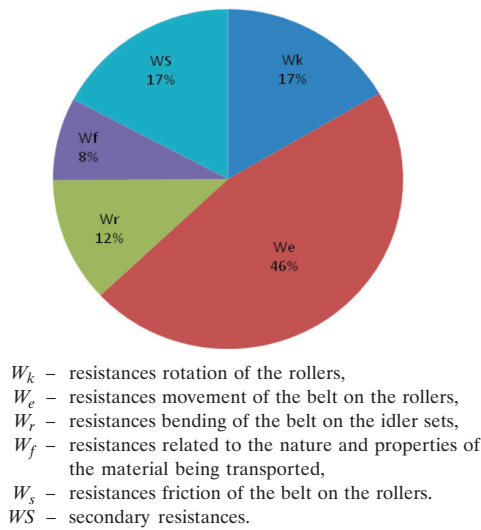


Fig. 3. The components in the total movement resistance of a fully loaded horizontal conveyor in an open-cast lignite mine

Figure 3 highlights the belt movement resistances W_e , resulting from the indentation of the belt into the roller, which accounts for nearly 50% of the total conveyor movement resistance in this case. For this reason, most of the actions to reduce the energy consumption of the conveyor have focused on the development of energy efficient belts characterized mainly by reduced-thickness covers and made of rubber blends with appropriate properties. The use of energy-efficient belts will reduce this component of the resistance to movement by about one-third compared to a standard belt [1, 3–8]. Some belt manufacturers also consider the possibility of building belts with a special energy-efficient core, which are lighter and cause a reduction in the resistances of bending and belt movement – W_r , W_e [9].

Limiting the value of the conveyor's movement resistance can be achieved by using rollers with diame-

ters larger than the standard, resulting in a reduction of bending resistances – W_r , belt movement resistances – W_e , and roller rotation resistances – W_k . There is also ongoing research on design solutions for rollers with reduced rotation resistances through the use of special bearings and seals [10, 11].

The DIN 22101 standard [12], which describes the basic method of calculating belt conveyors, indicates the directions for reducing the main resistances of the conveyor by:

- properly setting the conveyor route structure,
- limited bias angle for each of the side rollers,
- increasing the distance between the roller sets,
- increasing the roller diameters,
- increasing the tension force on the belt,
- reducing the speed of the belt,
- limiting the trough angle.

While ensuring the proper alignment of the conveyor and increasing the roller diameter is unquestionable, it should be noted that modifying any other parameters can lead to unfavorable consequences. Increasing the distance between idler sets leads to increased loads and requires greater tension force on the belt, decreasing belt and joint durability, and increasing the load on the drums. In contrast, decreasing speed and trough angle can reduce conveyor transport capacity.

2.2. Secondary resistances

In the case of short conveyors with high capacity, the resistances that often determine the value of the selected drive power are secondary resistances – W_s , which occur at certain points of the conveyor such as: the head and tail stations, the drum drive system, the take-up device, and the loading and unloading stations. The main components of these resistances are:

- resistances at the loading point, associated with the acceleration of the transported material,
- resistances at the loading point caused by the friction of the transported material on the skirtboards,
- resistances related to the pressure of the material in the loading hopper,
- resistances of scrapers, strips, and other cleaning devices,
- resistance to belt bending on the drums,
- resistance to drum rotation resulting from friction forces in bearings and seals.

In addition, additional resistances – W_D , resulting from the installation of special equipment such as:

- idler sets for the centering belt,
- installations for reversing belt,
- plows or discharge carts etc., can also be included in secondary resistances.

In the case of belt conveyors operating in open-pit mines with a capacity of approximately 20,000 t/h, the loading resistance is also important, and is included in the secondary resistances W_S . The direction of modernization of transfer points, in terms of reducing their energy consumption, focuses on shaping the flow of the load by changing the angle of inclination of the baffle bar and increasing the horizontal component of the velocity of the load in place of falling onto the receiving belt and reducing the height of the lifting load, which will reduce the loading resistances by half compared to the currently used solutions [13, 14].

Undoubtedly, reducing secondary resistances is achieved by constructing the longest conveyors possible, contributing to a reduction in the number of transfer points, drums, and belt cleaning devices.

2.3. Gradient resistance

In belt conveyors with a significant incline angle, the basic component of motion resistance is gradient resistance (W_H), related to the lifting or lowering of the conveyed material in inclined sections of the conveyor route. Unlike other types of resistance, gradient resistance can have a positive or negative value depending on the sign of the angle of the slope of the route.

The resistance of lifting the material significantly changes the structure of the conveyor's motion resis-

tance components (Fig. 4). In the case of a conveyor with motion resistance components presented in Figure 3, a change in the average slope angle of the conveyor by 2° resulted in the percentage contribution of belt movement resistance dropping from almost 50% to 20% of the total resistance. In the case of a conveyor inclined at an angle of 5° , these resistances represent only 10% of the total resistance, as 80% of the drive power is used to lift the material, and only 20% is consumed to overcome the main and secondary resistances of the conveyor.

The given example concerns a fully loaded high-capacity lignite open-pit conveyor. In the case of lower capacities and a smaller fill factor value, the percentage values of individual components' contributions may differ from those given in the above example. Nevertheless, regardless of the conveyor construction variant used, the effects of using energy-saving belts and idler sets will be clearly noticeable only for long, horizontal conveyors with a slight incline angle.

The belt conveyor is a transport device that is well suited to the topography of the terrain. Therefore, a relatively large group of belt conveyors transport material downwards at an average slope angle greater than -5° . In such a situation, there is an opportunity not only to limit consumption but also to recover energy. For example, at the Los Pelambres mine in Chile, a 13 km long belt conveyor system transports copper ore from a mine located at an altitude of 3200 m above sea level to a processing plant 1310 m below. The location of the conveyors has resulted in the need for 10 engines with a power of 2.5 MW each working as generators. In 2007, the transport system generated 90,000,000 kWh [2].

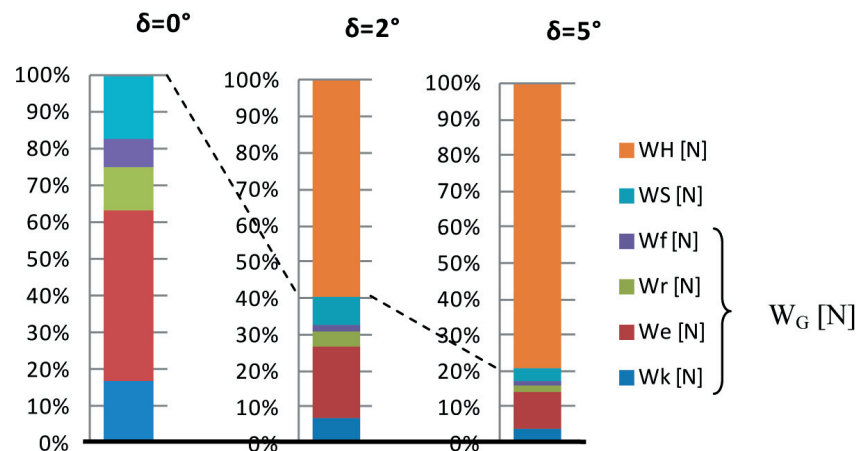


Fig. 4. Structure of the motion resistance of a horizontal and inclined conveyor at angles of 2° and 5° according to QNK TT

3. TRANSPORT CAPACITY OF A CONVEYOR BELT

Another parameter, besides the conveyor's rolling resistance, which has a significant impact on the energy consumption of the conveyor, is the amount of transported material, that is on the conveyor belt. Due to the operating system and the organization of the crew's working time, the transport capacity of belt conveyors is not fully utilized. An example of the average performance changes of three belt conveyors working in an underground mine is presented below (Fig. 5). The theoretical maximum capacity of each conveyor is 2,500 Mg/h, but the degree of utilization of the transport capacity does not exceed 60%.

To reduce the energy consumption of the conveyors, it is necessary to minimize their operation without material (the energy consumption index of the

conveyor without a load tends toward infinity) and ensure at least a 40% loading level of the conveyor (Fig. 8). This can be achieved by stabilizing the material flow using retention silos or by using a belt speed control system. Stabilizing material flow using retention containers will reduce the energy consumption of all conveyors downstream of the silos, while regulating the belt speed to increase the load level will reduce the power consumption of only one conveyor. The problem of regulating the belt speed as a function of the feed rate is quite complex and multidimensional, being dependent on the rolling resistance and efficiency of the drive system [15]. The character of the energy consumption curve indicates that it is undoubtedly worth ensuring a minimum 40% loading level of the conveyor, while the value of the optimal filling of the trough depends on the type of conveyor, its configuration and location, and the components used.

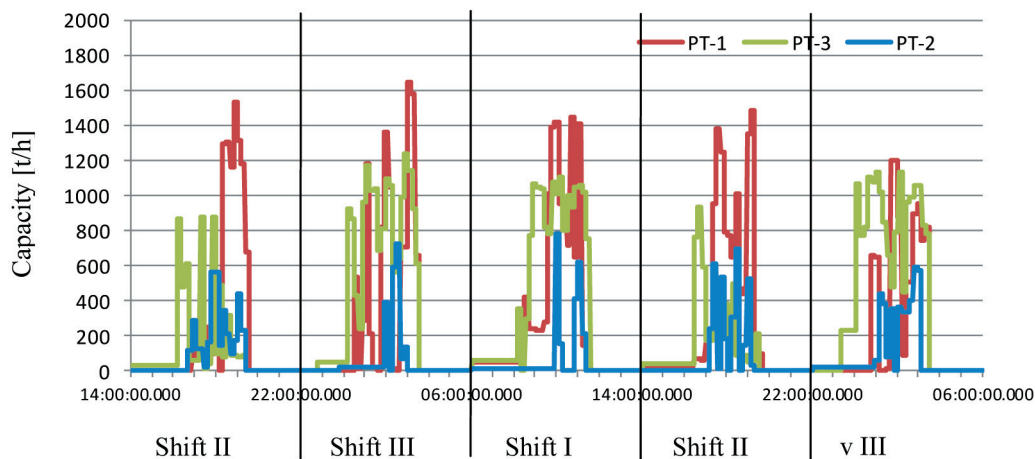


Fig. 5. Changes in the capacity of three example conveyors during five work shifts

4. EFFICIENCY OF THE DRIVE SYSTEM

During the industrial research conducted on a conveyor belt, it was found that obtaining full filling of the belt trough over its entire length is a major challenge. As a result, the drive system is not fully loaded and often well below the nominal values of motor and gearbox loads. Using a mobile system for measuring the parameters of the belt conveyors, a series of tests were carried out on the selected conveyors, based on which the total efficiency of the multi-drum conveyor drive system was determined as the ratio of the mechanical power applied to the belt to the active power measured on the electrical distribution panel (Fig. 6) [16]. The measurement results indicated that losses in the drive system can be a significant cause of increased energy consumption of belt conveyors,

and the phenomenon of reduced drive system efficiency intensifies when operating below 30% of the nominal load.

A typical conveyor drive system consists of an induction motor, a coupling, a gear, and drive drums, and may also be equipped with a frequency inverter controlling the motor's operation or a hydrodynamic starting coupling (Fig. 7). The total drive efficiency is the product of the efficiency of the individual components of the system, so reducing the energy consumption of the drive can be achieved by increasing the efficiency of each element.

The frequency inverter's efficiency is highest at the nominal load and a frequency of 50 Hz. At a frequency reduced to 25 Hz (halving the belt speed), a decrease in efficiency of up to 81% at 25% motor load should be expected [17].

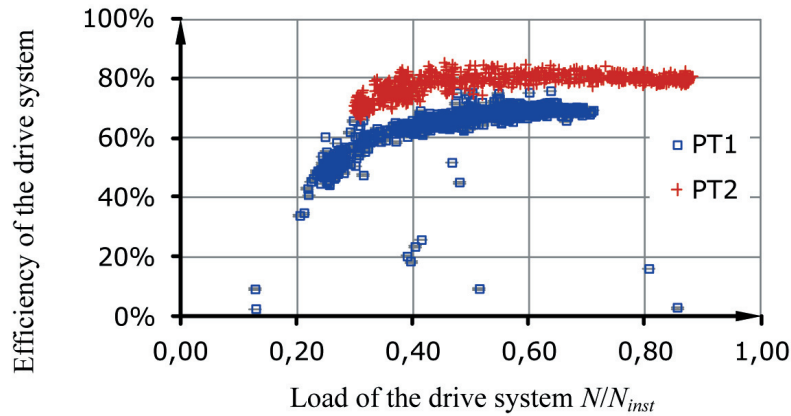


Fig. 6. Total efficiency of the conveyor drive system determined based on industrial research [2]

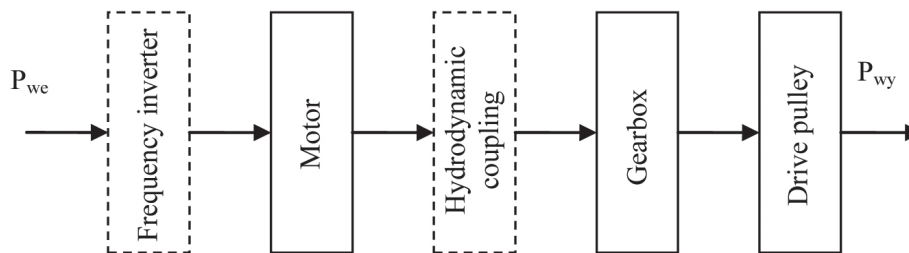


Fig. 7. Block diagram of the conveyor drive system

In simplified terms, the efficiency of an induction motor depends on the transfer load, rated power, motor type, and the number of pairs [2]. Higher motor power and higher synchronous speed mean higher efficiency. The motor efficiency can be increased by 4% to 6% using energy-efficient motors [18].

The hydrodynamic coupling only transmits torque when there is a slip between its pump and turbine parts. The nominal slip of the coupling is between 2% and 3%, so during the steady operation of the conveyor, its efficiency is greater than 97%, as the slip decreases at loads below the nominal.

The mechanical efficiency of the gearbox depends on the transferred load, the rated power, the gear ratio, the number of stages and the rotational speed and operating temperature. The lower the gear ratio and speed, the higher the efficiency of the gearbox.

The final element of the drive system is the drive drum. The efficiency of converting torque into driving force depends, among other things, on the belt bending resistance, its properties, tensile force, bearing resistance of the drums, their diameter, and energy losses associated with transferring driving force from the drum surface to the belt. As the research results have shown, the proper design and selection of the drum and belt, as well as adequate tensioning, can significantly improve the efficiency of the drive system.

5. SUMMARY

Possible directions to reduce the energy consumption of a conveyor belt can be illustrated based on the example graph shown in Figure 8. A conveyor with an energy consumption characteristic described in curve B can be subjected to modernization involving reducing resistance and increasing drive efficiency (1→2), resulting in a reduction in energy consumption without changing the degree of load of the conveyor (state A). Alternatively, one can retain the characteristics of energy consumption B (without modernization) and increase the average degree of loading of the conveyor by organizational-technological changes in its operating parameters (1→3).

It is almost indisputable that there is a need for energy-efficient solutions in the operation of conveyor belts. This article presents potential directions for reducing the energy consumption of conveyors, which should be chosen individually, taking into account the specific conditions of the operation of a particular conveyor. Better conveyors equipped with modern components can be built and provided with the best possible working conditions, or one can take advantage of the existing resources in the work organization of the mining site.

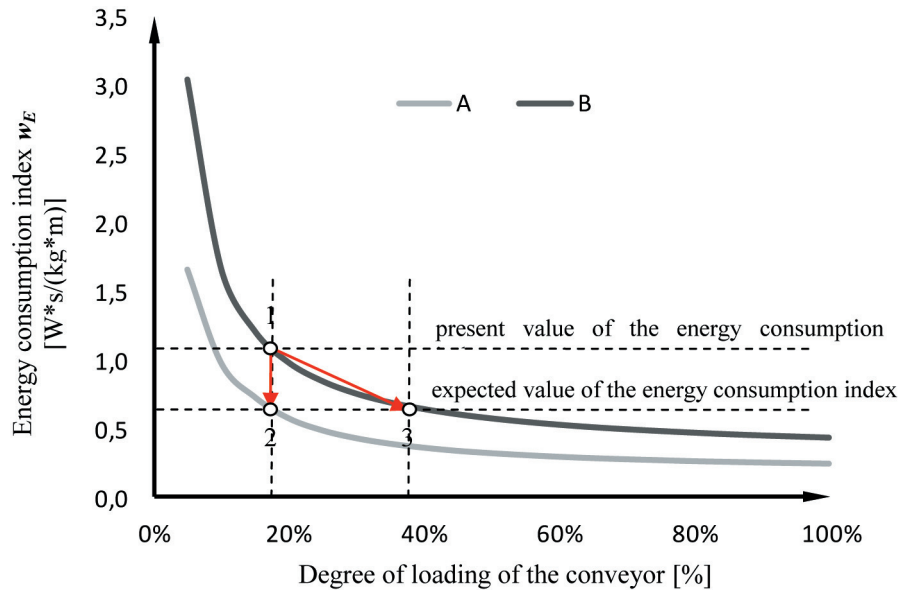


Fig. 8. Energy consumption index before (B) and after (A) modernization of the conveyor

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