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THE MAIN DIRECTIONS OF INCREASING THE OPERATIONAL EFFICIENCY OF HIGH PRODUCTIVE BELT CONVEYORS IN THE MINING INDUSTRY

When transporting bulk cargo at long distances, modern high productive belt conveyors must be equipped with energy-saving conveyor belts, which can reduce the energy consumption of the belt drive by 28%, and reduce the negative impact on the environment, including with ESG principles. Formula is proposed to determine the mass of emissions of harmful substances into the atmosphere - carbon dioxide, nitrous oxide and solid particles depending on the type of fuel burned to generate electricity. The use of supporting rollers on conveyors with a shortened middle roller, as well as with lower resistance coefficients to the rotation of the rollers, allows an additional 5-7% energy savings. The issue of saving energy consumed by the belt conveyor by optimizing the control and monitoring of the belt speed, as well as the processes of starting and braking the conveyor belt, is considered. Installation of gearless drives equipped with synchronous motors at high productive belt conveyors of long length allows to increase the efficiency of the drives, as well as to eliminate the work of gearboxes, starting couplings, which significantly reduces capital and operating costs.

Keywords: *conveyors, energy saving belts, belt cover, energy consumption, carbon dioxide, emissions, atmosphere, rolling resistance, idlers, belt speed, drive, gearless drives, synchronous motors, stator, rotor, efficiency*
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Introduction

Recently, for the transportation of bulk cargo at distances of 1000 m or more, belt conveyors of various types are used: rectilinear, tubular belt, steep incline belt, as well as belt conveyors with curves along the route, which are used most often because of the ability to transport minerals without overloading at distances up to 28 km, in one rate with a capacity of 15.000 t/h, and more [1, 2]. Conveyors of this scale are quite energy-intensive, therefore directly or indirectly they negatively affect the environment.

In accordance with this, the article is devoted to the analysis of the market of developments that make it possible to increase the operational efficiency of high productive conveyor belts through the use of energy-saving conveyor belts, innovative design and technological developments supporting idlers, speed control of the belt, as well as gearless drives with synchronous motors.

Consideration of the issue

The use of energy-saving belts not only reduces the consumption of electricity by the conveyor, and the amount of fuel burned for its production (coal, oil, gas, nuclear fuel), but also reduces the amount of carbon dioxide (CO_2) emissions into the atmosphere, and harmful particles of combustion products – nitrous oxide (NO_x) and solid particles (S_p).

To study the energy-saving properties of the conveyor belt in Germany, a special test and stand were developed, described in the standard [3, 4], representing a method for determining the rolling resistance of conveyor belts by supporting rollers, taking into account the width of the belt, the

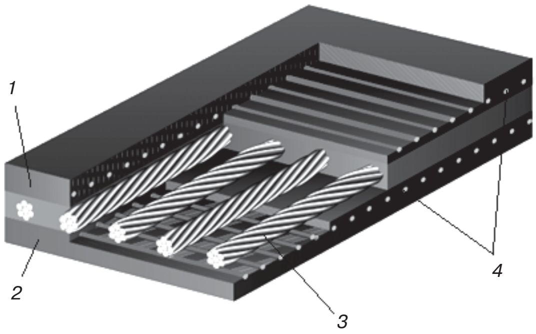

Fig. 1. The design of the energy-saving rubber belt type XLL of the German company ContiTech:
1 – the upper lining; *2* – the lower lining, *3* – the frame of the belt made of steel cables; *4* – synthetic cables that ensure the transverse rigidity of the belt

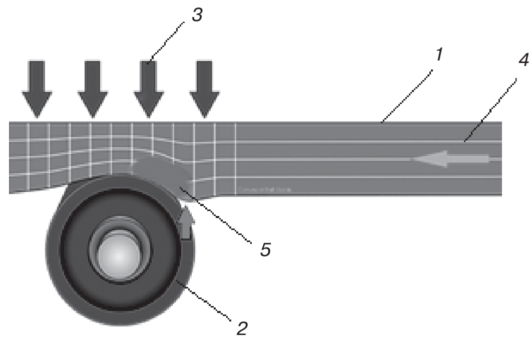

Fig. 2. Illustration of the belt indentation zone into the supporting roller of the cargo branch:
1 – belt, *2* – roller, *3* – linear load on the belt, *4* – the direction of movement of the belt, *5* – the indentation zone

loads on the roller and the ambient temperature. The method is designed to obtain the values of the coefficient of resistance to rotation of the roller and the resistance to indentation [4].

Belts of this type have special viscoelastic properties, which reduces the energy consumption of the conveyor belt by 28% compared to conventional conveyor belts. The specified viscoelastic properties of the considered tape are provided due to a special manufacturing technology of its lower lining, which allows reducing the zones of indentation, as well as the design of the tape itself [4–6]. For this purpose, special synthetic cables are positioned along the width of the belt between the core of the belt and its upper and lower plates, which allows providing the necessary transverse rigidity, eliminating the collapse of the belt and deflection between the rollers on the cargo branch of the conveyor (**Fig. 1**).

Currently, the energy-saving tapes are produced by German companies ContiTech and Pxoenix, which are labelled as LRR, XLL, and EOB, using a special technology for manufacturing the lower lining of the tape, which provides for reducing energy losses when it comes into contact with the roller [7].

The use of NR/BR rubbers for the manufacture of the lower lining of the belt makes it possible to reduce the rolling resistance component by the factor of the roller indentation into the lower lining of the belt, this especially affects conveyors with a length of more than 1000 m, in which it can range from 50% to 70% of the total resistance coefficient of rotation of conveyor rollers [6].

Reducing the resistance of the belt movement allows the use of lighter belts, rollers, drive drums, etc. [6], which significantly reduces the energy consumption of transportation.

Figure 2 shows an illustration of the zone of indentation of the conveyor belt into the roller support of the cargo branch of the conveyor.

The use of such belts allows dramatically reduce energy consumption by the conveyor, which leads to a reduction in emissions, and in particular CO_2, into the atmosphere, when burning fuel at power plants to generate electrical energy.

The mass of emissions of harmful substances ($m_{h.s}$) into the atmosphere – carbon dioxide CO_2, nitrous oxide NO_x, and solid particles, as it is known, depends on the type of fuel, the amount of energy E_C consumed by the conveyor belt, and the specific emission factor k_E [8]:

$$m_C = k_{h.s} \cdot E_E. \tag{1}$$

The specific emission factor k_E depends on many factors and considerably on the type of power plant and the fuel itself (coal, oil and gas, nuclear power, hydropower).

For example, in the Netherlands, the specific emission factors k_E for CO_2, NO_x, and s_p respectively are 0,15, 0.00016 and 0.0000018 [8].

The **table** shows data on the amount of carbon dioxide and solid particles emissions into the atmosphere for various sources of electricity generation, attributed to 1 MW · h of generated energy based on EU data [9].

Since in our country the main primary resource for energy production conveyor is coal, the amount of emissions of gases and solids is very significant, and, therefore, the savings from the considered proposals is substantial.

Innovative developments of supporting idlers are designed to choosing: the idlers geometry; bearings taking into account the operating loads; non-contact seals and effective lubricants, allowing for a low coefficient of resistance to the rotation of the rollers, which also leads to a reduction in power consumption and an increase in the service life of the belt.

The studies carried out at Moscow State Mining University (MSMU) [10] allowed us to obtain dependencies for calculating the maximum theoretical cross-sectional area of the load on the belt, as well as for determining the optimal ratio between the lengths of the middle and side rollers, at which the load alignment on the bearings of all 3 support rollers is achieved.

The amount of emissions for various sources of electricity generation attributed to 1 MW · h of generated energy

Primary resources for energy production	Mass of CO_2 emissions into the atmosphere, kg/MW·h	Weight of solid particles released to the atmosphere N/MW·h
Coal	1083.7	819.9
Oil	711.0	695.4
Gas	585.4	144.2
Nuclear power	9.8	54.6
Hydropower	3.7	20.6

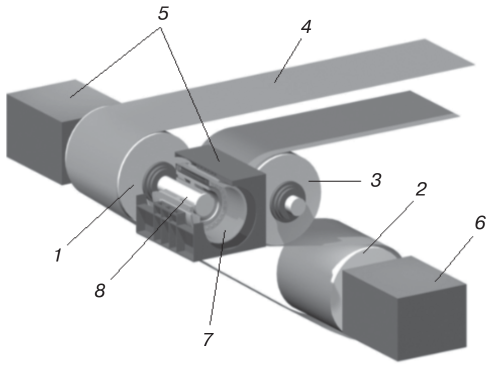

Fig. 3. The layout of a 2-drum gearless drive belt conveyor equipped with synchronous motors:
1 – the first drive drum; *2* – the second drive drum; *3* – deflecting drum; *4* – conveyor belt; *5* – synchronous motors of the 1st drive drum; *6* – synchronous motor of the 2nd drive drum; *7*, *8* – stator and rotor of the motor

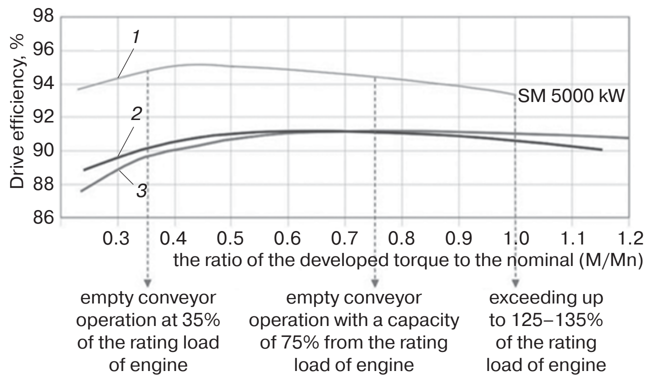

Fig. 4. The efficiency of the gearless synchronous motor drive conveyor depending on the torque on its shaft, for the case of installing one synchronous motor with a capacity of 5000 kW, in comparison with the drive equipped with 2 asynchronous motors of 2500 kW with gearboxes:
1 – synchronous motor; *2* – slip-ring motor + mechanical transmission; *3* – asynchronous motor + mechanical transmission

At the same time, it was found that the component of resistance to the movement of the belt from deformation of the load and the belt when they move along idlers with a shortened middle roller is on average 5% less than on 3-roller support with the same rollers. In addition, the resulting deeper trough centers the moving conveyor belt better.

Of great interest are also the new technologies being developed for the production of energy-efficient and reliable conveyor rollers. For example, the rollers of the German company «GURTEC» HM series are distinguished by an original design with excellent characteristics: they have a long service life, low weight (which also increases energy efficiency due to a lower coefficient of resistance to rotation of the rollers), low noise and vibration [11].

The highly automated production process uses the technology of flow forming of tubes and ensuring their absolutely round shape, as well as a special process of forming their ends, eliminating the need for welding. Such rollers do not require machining and balancing, since the tube wear is extremely low, and its thickness remains constant during long-term operation, which leads to an increase in their service life. The NM series, known in the industry as «Rolls-Royce», is designed specifically for the mining industry for extreme loads and high belt speeds – up to 11 m/s with a capacity of up to 52000t/h.

Energy savings of the belt conveyor can be additionally achieved by optimizing the management and control of the belt speed and its acceleration of start-up [12, 13], which can be adjusted discretely (on/off) or continuously. Usually, a conveyor belt runs at more or less the same speed regardless of whether its belt is fully loaded or empty.

Control the linear load on the belt using conveyor scales or a system for measuring the volume of material lying on the belt, and also adjust the speed of the belt so that the belt is always filled with the optimal volume of cargo, considering the threshold value of the degree of loading of the belt, for example 85%. If the tape loading goes beyond the specified range, for example 10%, then the tape speed control system is activated, correcting its deviation.

When adjusting the speed of the belt movement depending on the actual cargo flow coming to the belt, and especially in the case of its reduction – dust formation in the overload nodes decreases, which has a positive effect on the ecology of the environment, as well as on the service life of the conveyor belt, rollers and drums

Conveyor belts are usually driven by asynchronous motors with a short-circuited rotor. In order to realize a change in the speed of the conveyor belt, it is necessary to be able to control the frequency of the motor supply using a frequency converter. Currently, the prices of frequency converters are comparable to the prices of other traditional assembly units of belt conveyor drives – hydraulic couplings. To assess the payback of investments in frequency converters, an accurate calculation of the benefits of regulating the speed of the tape is necessary.

Reducing the conveyor energy intensity of gearless drives using synchronous motors can be of great importance.

About five years ago, "Siemens" and "Thyssenkrupp" justified the prospect of increasing the length and productivity of belt conveyors for the mining industry and developed the "Directdrive" drive [14].

As the name implies, the drive power required for the operation of a high-performance belt conveyor is transmitted to the drive drum directly without a gearbox.

A little earlier, notably in 2012, the German company "Takraf" received a contract from the Chilean mine operator "Codelco" for the development and manufacture of a belt conveyor system equipped with 11 gearless drives for the world's largest underground copper mine "El-Teniente" with a capacity of 12,000 tons/hour at a distance of 11.5 km. For the specified operating conditions, a unique drive of each conveyor belt with a synchronous motor with a capacity of 2500 kW and one bearing in the motor – drive drum system was implemented. The layout of such a drive is shown in **Fig. 3** [15].

The advantages of gearless drives compared with traditional electromechanical drives are reduced not only to the possibility of installing more powerful synchronous motors, but also by increasing their efficiency by reducing the transmission chain.

Figure 4 shows the dependences of efficiency for drives with different types of motors in relation to their torque, which shows the advantages of synchronous belt conveyor drive, across the entire spectrum of values under consideration.

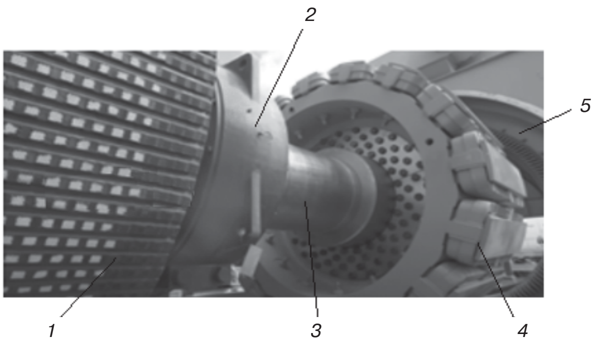

Fig. 5. Structural components of the synchronous motor of the conveyor belt:
1 – driving drum; *2* – highly elastic coupling; *3* – rotor shaft; *4* – motor rotor; *5* – motor stator

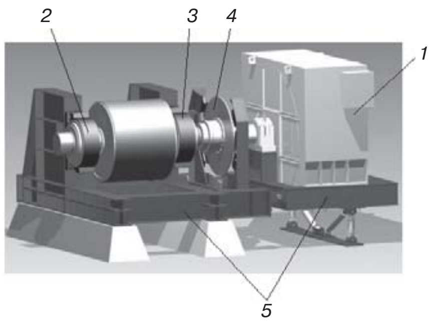

Fig. 6. Drive model of a belt conveyor equipped with a synchronous drive with one external bearing:
1 – synchronous motor; *2* – external drum bearing; *3* – coupling; *4* – disc brake; *5* – Frame of the drive drum and motor; *6* – drive drum

It can be seen from Fig. 4 that the efficiency of a gearless synchronous drive is much higher than traditional conveyor drives with a phase-wound rotor, or drives equipped with motors with a short-circuited rotor, equipped with gearboxes and turbo couplings.

Belt conveyors, as noted, do not always operate at full load during operation. Partial load conditions and even (short-term) periods of downtime are all part of the operation mode of the conveyor belt.

While asynchronous motors operate with lower efficiency, the efficiency of synchronous motors increases, due to their increasing efficiency in general, and especially in the range of increasing loads. In addition, the absence of a gearbox and turbo couplings in their drive eliminates the occurrence of loads in these nodes during the transmission of torque, which leads to a sharp reduction in capital and operating costs of the belt conveyor drive.

The main feature of the gearless drive is the principle of operation of the synchronous motor, lies in the fact that the latter is made without bearings, and its rotor is directly connected to the shaft of the drive drum by means of a flange connection or a highly elastic coupling – finger or diaphragm, **Fig. 5, 6**. The second end of the drum shaft is mounted in an outrigger bearing support (see Fig. 6) [16].

It should be noted that the assembly and installation of gearless belt conveyor drives are associated with certain conditions, which are as follows:

• the need to comply with the permissible deviations of the air gap between the stator and the motor rotor. A larger air gap between the stator and the rotor of the synchronous motor reduces the structural loads that the mechanical drive units of the conveyor belt must comply with, and especially on the shaft of the drive drum;

• when installing the drive, the drive drum is primarily connected to the motor rotor, and only after that the latter is placed in the stator housing rigidly mounted on the foundation of the base.

Conclusions

Taking into account the materials presented in the article, the following conclusions can be drawn to improve the efficiency of operation of high-performance belt conveyors in the mining industry:

• high-performance belt conveyors with lengths exceeding 1000 m. must be equipped with energy-saving rubber or aramid belts;

• the use of energy-saving conveyor belts labelled LRR, XLL, and EOB reduces energy consumption by a belt conveyor drive by 28%, which also has a positive effect on reducing carbon dioxide and particulate emissions for all sources of electricity generation of belt conveyor drives and complies with the principles of the ESG program;

• formulas are proposed to determine the mass of atmospheric emissions of harmful substances, such as carbon dioxide CO_2, nitrous oxide NO_x, and s_p, depending on the type of fuel burned to generate electricity, as well as to assess their harmful effects on the environment;

• the use of supporting idlers with a shortened middle roller, as well as with lower coefficients of resistance to rotation of the rollers, allows additionally save 5-7% of the energy spent on cargo transportation, which also has a positive effect on operating costs and reducing the negative impact on the environment;

• additional savings in energy consumed by a belt conveyor can be achieved by optimizing the mode of starting and braking of the conveyor belt, management and controlling the speed of the belt, which has a positive effect on its service life, as well as conveyor rollers and drums;

• the use of gearless drives equipped with synchronous motors on high-performance long-length belt conveyors (over 5000 m), allows increase the efficiency of the drives, as well as exclude gearboxes, starting couplings, control systems, from their acquisition, which significantly affects capital and operating costs and simplifies the control system.

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ON SOME ASPECTS OF INCREASING THE TARGET PRODUCTIVITY OF UNMANNED MINE DUMP TRUCKS

This article considers one of the approaches to solving the problem of improving the efficiency of the functioning of unmanned open pit transport. The actual data on the movements of robotic dump trucks within the framework of a continuous transport and technological cycle at one of mining sites of a coal mine are analyzed. During the study, the movement times in the loaded and empty states are recorded. In addition, the time of passing by dump trucks of individual sections of the transport route is monitored, in order to empirically determine the speed reserves for each robot. As a result, several options have been obtained to increase the target performance of an autonomous dump truck by changing the speed modes of movement in certain sections. One of the variants is presented in the paper as an illustrative example. The paper also briefly discusses possible approaches to formalizing the procedure for determining the optimal driving modes of robotic dump trucks, depending on the terrain and features of the route as well as the roadbed condition.

Keywords: *robotic dump truck, digital transformation, optimization models, open-pit mining, Industry 4.0, quarry, route segments, unmanned mining transport systems, robot target productivity, autonomous haulage systems*
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Introduction

At present, the development and implementation of technologies for rock mass haulage using robotic open pit mine equipment is a steady industrial trend in a number of leading countries in the open-cast field, such as Australia, Canada, South African Republic [1–3]. The leaders in the development of robotic and autonomous large dump trucks are such well-known companies as Komatsu (Japan), Caterpillar (USA), Euclid-Hitachi (Japan), BELAZ (Byelorussia) [4-6].

In comparison with the existing technologies of mining and carrying of minerals, robot dump trucks can potentially provide higher efficiency of mining under the condition of rational organizational management, as they allows to reduce operating costs by cutting-down the equipment downtime due to human factors [4, 7–9]. In the last 5–7 years, a number of engineering companies, such as Modular Mining Systems, Wenco MiningSystems, Vist Robotics, ASI