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Evaluating the Efficiency of Coal Loading Process by Simulating the Process of Loading onto the Face Conveyor with a Shearer with an Additional Share

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P A P E R   I N F O

A B S T R A C T

This paper analyses the possibility of increasing the efficiency of loading the destroyed rock mass into the face scraper conveyor by the lagging screw actuator of the shearer in the process of coal mining in the complex mechanized treatment faces of coal mines. It was taken into account that the most significant influence on the loading efficiency of coal is exerted by the dimensions of the cross-sectional area of the loading window, the distance between the screw and conveyor and the height of the bottom of the conveyor. Non-traditional technical solutions are proposed that reduce the negative impact of the gap between the screw and the conveyor on the efficiency of coal loading by the lagging screw actuator of shearers and increase the degree of filling of the conveyor groove. Technical solutions contribute to the formation of a rational section of the cargo flow in the trough of the downhole conveyor and, therefore, increase its productivity. The results of modeling the process of loading coal onto the face conveyor by an auger actuator with an additional loading device are presented. Evaluation of the effectiveness of the proposed constructive technical solutions for the interface unit in the loading area confirmed an increase of 2.94 times the maximum capacity of the screw executive body for loading coal onto the face conveyor while 2.7 times less specific energy consumption during loading.

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1. INTRODUCTION

The mining of high-tech coal seams in countries with a developed mining industry is carried out mainly by long complex mechanized treatment faces equipped with dual auger shearers [1-5] with symmetrical layout. Such shearers can work on one-sided with stripping and shuttle schemes of coal extraction, with self-cutting into a seam on a new strip of excavation by oblique drives. Such combines are technological, highly productive, and their screw augers are simple in design, reliable in operation, combined with the operations of separating coal from the massif, unloading it from the destruction zone and loading it onto the face conveyor [6-8]. According to the efficiency of the process of coal mining on medium and powerful formations, there is currently no alternative [9-11].

However, the auger actuators are also characterized by significant disadvantages associated, in particular,

with the operating conditions of the lagging auger actuator. These conditions are characterized by the following features:

- destroying a pack of coal along the soil, the lagging auger actuator loads it and part of the coal mass destroyed by the leading auger actutator onto the armoured conveyer;

- the mass of coal during loading moves "passively" along the channel formed by the interfaced equipment (becoming a conveyor, the gearbox actuator, auger actuator, retaining plate or blade), only under pressure created by the auger;

- the loading channel is structurally saturated with local resistances that cause circulation of coal in the flow, enhance its crushing, dust formation and increase energy consumption;

- the channel is open to move part of the destroyed mass to the bottomhole soil.

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The problem also lies in the fact that the gap between the auger actuator and the conveyor and the cross-sectional area of the loading window are formed in the process of assembling equipment units without taking into account the special requirements for the loading channel.

To date, there are no technical solutions and proven methods for choosing the structure and parameters of loading devices for shearers that provide a given level of efficiency of the coal loading process according to the criteria of the maximum possible productivity, minimizing the yield of small classes of coal and specific energy consumption energy taking into account additional resistance to the movement of coal flow in the loading channel [1, 12-14].

Over the last few decades, the shearer drum's coal loading performance has not been adequately studied. In fact, many conventional studies have either overlooked it or obtained it empirically. The main factors affecting it were studied by the end of the 1980s and earlier of the 1990s [6, 15, 16]. In these studies, the authors showed the impact of some factors, such as mining conditions, the shearer's operating parameters, and mining equipment on the shearer drum's loading rate using empirical, theoretical analysis and computer technology. As a result, some key factors affecting the shearer drum's coal loading performance have been noted and recommended to consider for future studies. Having considered those key factors, a Turkish company also stated that the distance of the drum from the scraper conveyor might influence the shearer drum's coal loading performance [6].

Moreover, it has been shown that there is a difference between drums with conical hub and cylindrical hub regarding the coal loading performance [16]. Furthermore, by utilizing a helical vane in the form of a varying pitch and a curved generatrix, it is possible to improve the shearer drum's coal loading performance. The influences of the pulling speed, rotation speed on the coal loading rate of the shearer drum were also presented by Liu and Gao [12]. Nevertheless, the abovementioned models have not shown a solution to completely reduce the amount of coal left on the cleaning conveyor and shearer drum [14].

Hence, in this study, we want to develop a technical solution to improve the efficiency of the shearer's loading process and then compare its performance with the one being used by DEM software (Discrete Element Method) to validate the accuracy and reasonableness of the proposed technology. The DEM software is a computer simulation that has been widely used in several fields, such as geotechnical engineering, geology, and machinery fields [12–17], and especially the screw conveying field [12–14].

Therefore, this article proposes the installation of an additional share in the transition zone between the auger

and the conveyor and evaluates the efficiency of the coal loading process by a shearer for two options: with an installed share and without a share.

Taking into account the insufficient study of the influence of the distance L from the auger actuator to the conveyor (Figure 1) and the configuration of the loading channel, the efficiency assessment was carried out using the modeling method. This made it possible to take into consideration the influence of the peculiarities of the nodes arrangement of the equipment in the considered zone on the process of passive movement of the destroyed mass to the conveyor.

The efficiency of the loading process also depends on the distance L_m, by which the coal flow during loading fills the trough of the downhole conveyor. This distance can be determined by the formula:

$$L_{\mathrm{m}} = \frac{h_{\mathrm{z}} + h_{\mathrm{k}}}{\mathrm{tg}\left(\rho + \beta\right)} - L \, , \, \mathrm{mm} \tag{1}$$

where β is the angle of inclination of the conveyor to the horizontal, degrees; ρ - depositional gradient, degrees; h_{z} - excess of the upper boundary of the surface of the cargo flow of the bottom face of the conveyor, mm; h_{k} - conveyor bead height, mm; L is the distance along the soil between the auger and the face conveyor, mm.

The shorter the displacement mass displacement path (L) to the downhole conveyor, the lesser the resistance to the movement of the coal flow during loading onto the conveyor and the lesser the volume of unloaded coal and the higher the efficiency of the loading process. However, in modern designs of shearers and conveyors, this distance remains substantially significant - 300 mm or more.

2. TECHNICAL SOLUTION

As a result of the analysis of known designs of shearer units in the loading zone, the installation of an additional share in the transition zone between the auger and the
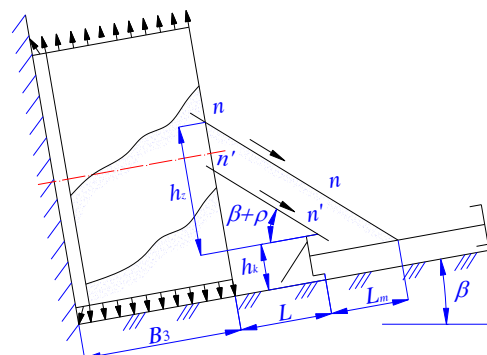
Figure 1. Scheme of the formation of cargo flow on the face conveyor

face conveyor, which may deviate from the initial position of its installation under the influence of oversize during its transportation, is proposed. The loading plate with additional share 1 is shown in Figure 2 in relation to a shearer with two screw actuators symmetrically located along its length and regulated by the thickness of the formation 7. The retaining flap 4 with an additional share 1 provide an increase in the efficiency of coal unloading from the transition zone, loading and formation of coal flow 10 on the bottomhole conveyor.

The loading device consists of a share 1, made in the form of a part of a truncated cone, a support bracket 6, a retaining flap 4, while the axis of symmetry of the working surface of the loading flap is parallel to the axis of rotation of the screw actuator 7. The share 1 is installed between the shield 4 and the face conveyor 9 at an angle less than 90 ° to its board and connected by a hinge 2 and rod 3 with a spring 11 with a bracket 5, which is attached

Figure 2. Loading device of a mining combine

to the housing 8 of the drive of the auger actuator. The lower edge of the share 1 is equidistant to the mating surface of the face of the conveyor 9 and is installed with a gap.

The auger actuator 7 (Figure 2), lagging along the direction of the combine harvester, destroys the lower layer of the coal seam, moves the broken mass by the auger blades with support on the loading plate 4 and ploughshare 1 to the downhole conveyor. In this case, the ploughshare reduces the resistance to movement of the flow of the destroyed mass to the downhole conveyor, reduces the circulation of coal in the flow and contributes to the formation of a rational cross-section of the flow.

The gap between the screw actuator and the bottomhole conveyor and the cross-sectional area of the loading window are limited in size due to the peculiarities of the layout of the equipment nodes, which creates increased resistance to the movement of the coal flow onto the conveyor. A loading plate with a ploughshare increase the efficiency of loading coal onto the face conveyor, as they provide:

- a more complete cleaning of the soil and loading of coal on the downhole conveyor;

- reducing the resistance to movement of the coal flow and, consequently, increasing the completeness of unloading of coal located in the zone between the conveyor side and the screw executive body, to the downhole conveyor;

- an increase in the fill factor of coal in the trough of the downhole conveyor;

2. 1. Simulation of the Process of Loading Coal with an Assessment of the Effectiveness of the Proposed Technical Solution   Modeling is carried out to evaluate the efficiency of loading coal with a shearer with an additional share in the transition zone between the screw and the face conveyor (Figure 3). When modeling, the EDEM 3D program was used. There are two forms, unit-wall, and particles, in EDEM. The wall is only represented by the surface. Particles are generally only represented by a sphere. In order to simulate the coal loading process of the drum, the drum had to be simplified (Figure 3). In this model, the tube hub consisted of the cylindrical surface, the blade comprised the helical surface, and the rear shield.

Figure 3 was a simulation model of the combined drum and coal wall. The coal wall was filled with identical diameter particles and bonded together using a common bond between the particles in the model. Since the simulation's focus was the coal loading of the drum, the cutting force of picks was not in the scope of the research. Meanwhile, to reduce the simulation time and improve simulation efficiency, the small values of adhesive bond strength of the normal direction and tangential were taken in the model. As long as the particles did not collapse before cut by the picks, the
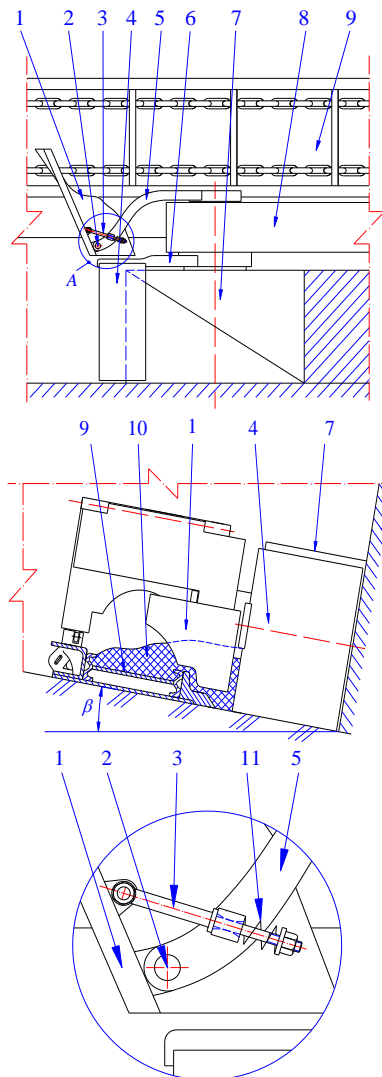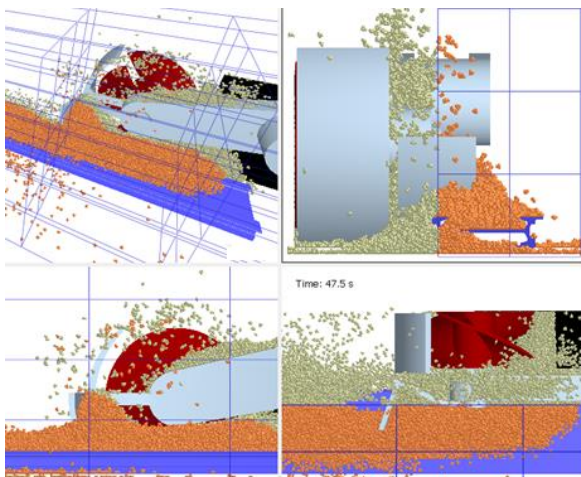
Figure 3. Feature of the process of loading coal with a lagging screw with an additional share

Figure 4. The dependence of the amount of loaded coal on the conveyor on time: 1. The amount of coal loaded onto the conveyor by a basic shearer;
2. The amount of coal loaded onto the conveyor by a combine with an additional share.

Figure 5. Change in torque on the screw: 1. Torque on the screw of the base shearer; 2. Torque on the auger of a shearer with an additional share.

bonding strength of normal direction was 8 Pa and the adhesive shear strength was 8 Pa in this paper. Statistical area of effective output particles can be set according to the simulation requirement, and statistics area was the outer side of coal wall in particle output direction in this study. Particles on the cleaning conveyor are colored orange for easy observation.

The process of loading coal onto the face conveyor is considered for two options: without a share and with an additional share. The following indicators were adopted as criteria for the process efficiency: productivity ($Q_\text{к}$), specific energy consumption (H_w) and secondary grinding (particle size distribution, W_{-d}).
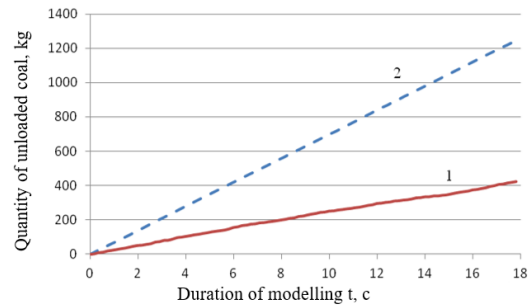
When simulating the process of loading coal onto the downhole conveyor, the following parameter values were adopted: screw diameter - 1800 mm, hub diameter - 600 mm, screw angle of the screw - $\alpha = 19\,°$, number of screw blades - 3, blade thickness - 50 mm, working width - 800 mm, auger rotation frequency - 60 rpm, conveyor bottom face height - $h_k = 350$ mm, conveyor pit width - 800 mm, combine harvester gearbox wall height - 350 mm, combine feed speed - 4 m / min; simulation time - t = 18 s.

Based on the simulation results of the process of loading coal onto the downhole conveyor, the dependences of the change in loading mass and the moment of resistance on the screw (Figures 4 and 5) over time are constructed.
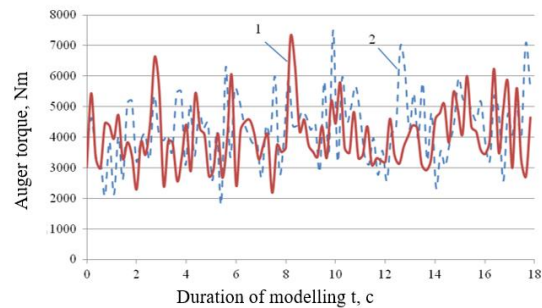
When modeling the energy intensity of coal transportation by a screw was determined by the formula:

$$H_W = \frac{P}{Q_K} = \frac{M \cdot n}{9550 \cdot Q_K}, \text{kW·h/t} \tag{2}$$

where: M_cp is the average value of the torque on the screw, Nm; Q_K - coal loading capacity on the conveyor by screw, t/h; n_ob - rotational speed of the auger actuator, rpm.

The average torque on the screw is determined by the formula:

$$M_\text{cp} = \frac{1}{n} \cdot \sum_{i=1}^{n} M_i, \text{Nm} \tag{3}$$

where: M_i is the current value of the torque on the screw, Nm.

The productivity of the lagging screw executive body for loading coal onto the conveyor was determined by the following expression:

$$Q_K = 3,6 \cdot \frac{m}{t}, \text{t/h} \tag{4}$$

where m is the mass of coal loaded onto the conveyor, kg; t - loading time, s.

As a result of modeling the process, taking into account the proposed design changes of the interface unit, it was found that the productivity of loading coal by the screw executive body on the downhole conveyor increases by 2.94 times, while the specific energy consumption during loading of coal by the combine decreases by 2.7 times.

TABLE 1. The results of modeling the process of loading coal onto the face conveyor using the proposed technical solution

Index	Basic shearer	Shearer with additional share
The average torque on the screw, N·m	4075.0	4333.7
Capacity for loading coal nto a conveyor, t/h	85.8	252.0
Specific energy consumption, kW·h/t	0.25	0.09

2. 2. The Discussion of the Results   As a result of the analysis of known designs of shearer units, a comprehensive solution is proposed aimed at increasing the efficiency of loading coal onto the face conveyor. This goal is achieved by the fact that in the auger actuator of the shearer containing the auger and loading guard, a share is installed between the guard and the face conveyor at an angle less than 90 degrees to its board. The share is installed above the conveyor with a gap. The lower edge of the share repeats the profile of the bead conveyor. The ploughshare is connected via an arm to the drive housing of the screw actuator. A loading plate with a ploughshare forms a flow without circulation of coal from the destruction zone to the downhole conveyor. Improving the efficiency of coal loading is achieved by increasing the completeness of soil cleaning, reducing grinding, dust formation and energy consumption.

3. CONCLUSIONS

The proposed technical solution is a lagging screw actuator with a loading shield and a share, provide:

- directivity of the flow with a decrease in resistance to the movement of coal from the destruction zone to the downhole conveyor;

- decrease in circulation and additional grinding of coal;

- increase the completeness of soil cleaning;

- reduction of dust formation and specific energy consumption·

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Persian Abstract

چکیده

در این مقاله امکان افزایش کارایی بارگیری توده سنگ تخریب شده در نوار نقاله خراشنده توسط محرک پیچ عقب برش در فرآیند استخراج زغال سنگ در تصفیه مکانیزه پیچیده معادن ذغال مورد بررسی قرار گرفته است. در نظر گرفته شد که مهمترین تأثیر در بازده بارگیری زغال سنگ توسط ابعاد سطح مقطع پنجره بارگیری ، فاصله بین پیچ و نوار نقاله و ارتفاع پایین نوار نقاله اعمال می شود. در این مقاله راه حل های فنی غیر سنتی ارائه شده است که تأثیر منفی شکاف بین پیچ و نوار نقاله را بر روی کارایی بارگیری زغال سنگ توسط پیچ عقب برش کاهش می دهد و درجه پر شدن شیار نوار نقاله را افزایش می دهد. راه حل های فنی به تشکیل یک بخش منطقی از جریان بار در دهانه نوار نقاله زیر چاهی کمک می کنند و بنابراین ، بهره وری آن را افزایش می دهند. نتایج مدلسازی فرآیند بارگیری زغال سنگ بر روی نوار نقاله توسط محرک اوگر با یک دستگاه بارگیری اضافی ارائه شده است. ارزیابی اثربخشی راه حل های فنی سازنده پیشنهادی برای واحد رابط در منطقه بارگیری ، افزایش ۲.۹۴ برابر حداکثر ظرفیت دستگاه اجرایی پیچ برای بارگذاری زغال سنگ بر روی نوار نقاله را تأیید میکند. در حالی که ۲.۷ برابر مصرف انرژی در هنگام بارگیری کمتر است.