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Experimental Studies of Effect of Shearer Auger Operating Device Effective Width on Effectiveness of Loading Process

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Abstract: Intensification of coal mining from mine seams of 0.55–1.20 m thick requires increasing efficiency of loose coal loading that may be achieved by selecting the optimal parameters of auger operating device of a shearer. The most reliable way to determine effect of the auger parameters on the energy parameters of the shearer operation is experimental research in actual operating conditions. As the subjects of the research, we selected up-to-date UKD400 and UKD200-500 shearers, operating in representative conditions of the Krasny Partizan mine of SE SVERDLOVANTRATSIT and Ternovskaya mine of DTEK PAVLOGRADUGOL PJSC. An adaptive method for specific mining operating conditions is proposed for determining the specific energy consumption of the shearers on material disruption and loading for thin seams in actual operating conditions based on fixing the values of currents of the cutting drive motors. Based on processing of the experimental data, an indicative dependence of the power for rock mass loading on the feed rate and the effective width of the operating device is determined. Increasing the auger effective width results in increasing the loading power and specific energy consumption. At the same time, the higher the shearer feed rate, the greater the growth of the loading power and specific energy consumption. This is due to the beginning of the process of loose rock mass circulation, and the larger the auger effective width, the more intensive the circulation process, and at the lower feed rate of the shearer the process starts. A method is proposed for selecting the auger optimum effective width based on the criteria of minimum specific energy consumption and maximum commercial productivity.

Keywords: shearer, auger operating device, productivity, shearer feed rate, specific energy consumption, loading power, effective width.

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Экспериментальные исследования влияния ширины захвата шнекового исполнительного органа комбайна на эффективность процесса погрузки

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Аннотация: Интенсификация добычи угля из шахтопластов мощностью 0,55–1,20 м требует повышения эффективности процесса погрузки разрушенного угля, что может быть обеспечено путем выбора оптимальных параметров шнекового исполнительного органа очистного комбайна. Наиболее достоверным способом установления влияния параметров шнека на энергетические параметры работы очистного комбайна являются экспериментальные исследования в реальных условиях эксплуатации. Объектами исследования выбраны очистные комбайны нового технического уровня УКД400 и УКД200-500, эксплуатирующиеся в представительных условиях шахт «Красный партизан» ГП «СВЕРДЛОВАНТРАЦИТ» и «Терновская» ПАО «ДТЭК ПАВЛОГРАДУГОЛЬ» соответственно. Предложена адаптивная под горнотехнические условия работы методика определения удельных энергозатрат разрушения и погрузки очистных комбайнов для тонких пластов в реальных условиях эксплуатации на основе фиксации значений токов двигателей приводов резания. После обработки экспериментальных данных установлена зависимость мощности на погрузку горной массы от скорости подачи и ширины захвата исполнительного органа показательного вида. С увеличением ширины захвата шнека мощность и удельные энергозатраты на погрузку возрастают тем интенсивнее, чем выше скорость подачи очистного комбайна. Это обусловлено началом процесса циркуляции разрушенной горной массы, при этом, чем больше ширина захвата шнека, тем процесс циркуляции интенсивнее и наступает при меньших значениях скорости подачи очистного комбайна. Предложен метод выбора рациональной ширины захвата шнека по критериям минимальных удельных энергозатрат и максимальной технической производительности.

Ключевые слова: очистной комбайн, шнековый исполнительный орган, производительность, скорость подачи комбайна, удельные энергозатраты, мощность на погрузку, ширина захвата.

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Articulation of issue

The main energy resource of the Donetsk region is coal, whose reserves, according to the DonUGI, are about 6.84 billion tons. The bulk of these reserves (about 83.2 %) is concentrated in seams 0.55–1.2 m thick [1].

Almost all of the Donbass coal seams have adverse mining & geological and geotechnical conditions and mode of occurrence. They are characterized by variable hypsometry, the presence of rock partings and solid inclusions in a coal mass [1]. These factors almost completely exclude the possibility of coal extraction using plow and modular complexes that leads to widespread use of shearers with auger operating devices as parts of powered complexes [1–5]. All of the above suggests the need for researches in the field of design and construction of shearers of a new generation, capable of working effectively in conditions of thin shallow seams.

The process of coal mining from seams 0.55–1.2 m thick by shearers can be described as highly energy-intensive [2–3]. This is due to the low loading capacity of the auger operating devices, which limits the shearer axis velocity within 2–5 m/min and as a result leads to low productivity of the shearer [2–3]. Intensification of coal mining from mine seams 0.55–1.2 m thick requires increasing efficiency of loosened coal loading that may be achieved by selecting the optimal parameters of auger operating device of a shearer.

Review of researches and publications

The issue of creating highly efficient stoping equipment was studied by many scientists [2–22]. The issues considered in [2, 3] relate to the design of narrow-web shearers operating in conditions of thin shallow seams extraction. In [4], the principles of designing the shearer traveling mechanisms are described. In work [5], the general tasks and principles of designing and engineering of mining machines and complexes of a new technical level are given. It was found [6–13] that auger operating devices, used in shearers for extracting thin and very thin seams, have greater breaking-down productivity than loosened rock mass loading productivity. The authors of works [14–22] were engaged in solving the problem of optimizing the loading process with auger operating devices based on determining the rational values of the geometric parameters of the augers and operating parameters of the shearer. The works [23–26] are aimed at solving the problems of automation of coal mining by shearers. In [27–36], an experience was described in the use of pulsed jets of a working fluid for breaking-down of a rock mass. However, there is no reliable data on the regularities of changing the energy parameters of a shearer operation when extracting thin shallow seams depending on the auger operating device width. The most reliable way to obtain the actual values of the energy parameters of the stoping equipment operation is experimental study in actual operating conditions.

The research aim (tasks)

Thus, the aim of this study is to determine regularities of effect of the auger operating device parameters on coal loading energy performance when extracting thin shallow seams.

The experiment description and findings

As the subjects of the study, up-to-date drum shearers UKD400 and UKD200-500 were selected, operating in representative conditions of the Krasny Partizan mine of the SE SVERDLOVANTRATSIT (Dolzhansky k^1_5 seam) and Ternovskaya mine of DTEK PAVLOGRADUGOL PJSC (C^B_5 seam). Summary on technical specifications of the considered shearers are given in Table 1.

In Fig. 1, breaking-down schematics and seam structures in conditions of the experimental studies of UKD400 and UKD200-500 shearers operation are shown.

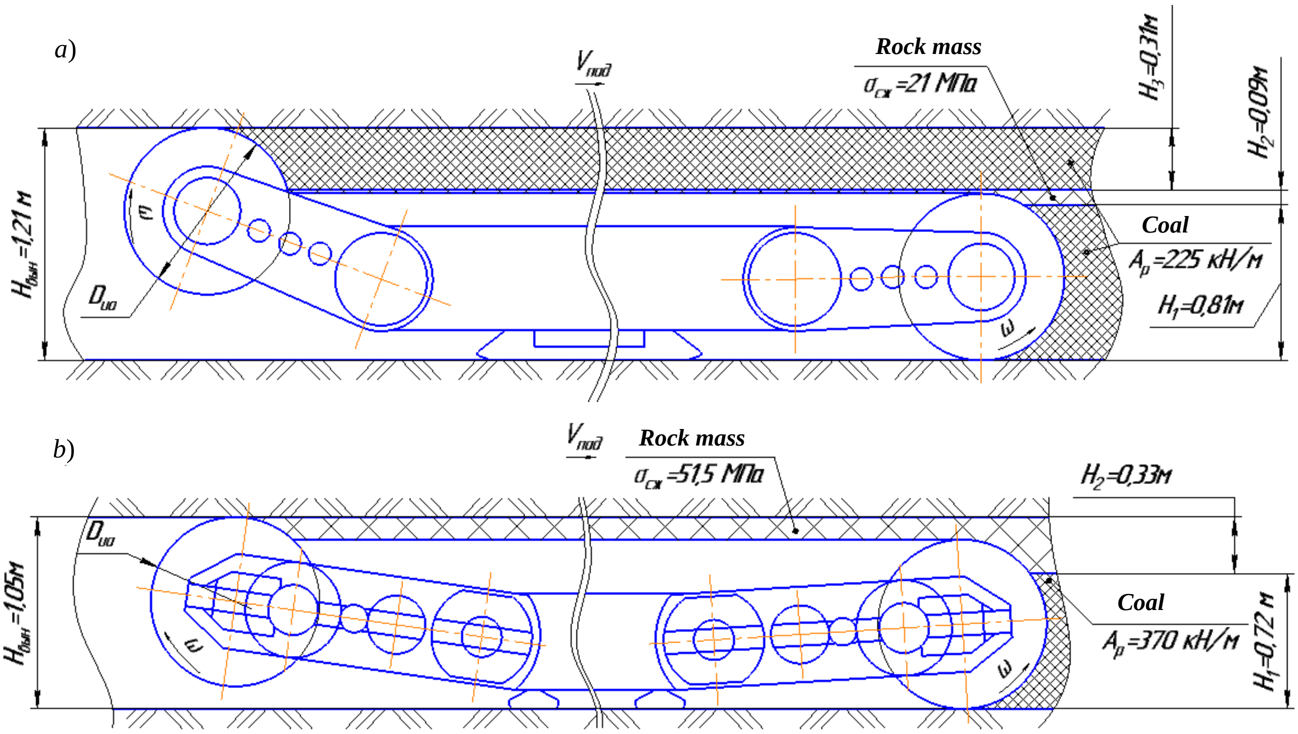

Fig. 1. Schematics of rock mass loosening by UKD400 (*a*) and UKD200-500 (*b*) shearers

Table 1

Technical specifications of the considered shearers

Parameter	Shearer type	
	UKD400	**UKD200-500**
Type of motor of operating device drive	EKV4-200V	SG7W490L-4
Rated power of cutting drives $P_{\text{ном}}$, kW	2×200	2×250
Motor rated current $I_{\text{ном}}$, A	129	155
Power factor cos φ, relative units	0.837	0.880
Operating device diameter $D_{\text{ио}}$, m	0.9	
Cut (web) width $B_з$, m	0.7	0.8
Auger blade angle of lead (by blade) $\alpha_п$, degrees	15°38′	13°54′
Auger angular rate ω, sec^{-1}	8.17	8.31

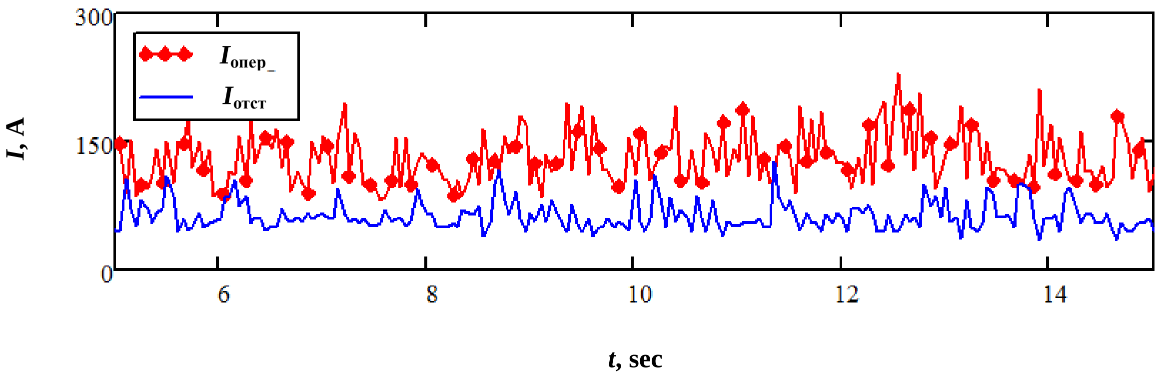

Fig. 2. A fragment of recording the values of motor currents of leading ($I_{\text{опер}}$) and lagging ($I_{\text{отст}}$) behind drives of UKD400 shearer operating devices

Table 2

Data of the experimental studies of UKD400 and UKD200-500 shearers operation

Parameter	Shearer type						
	UKD400			**UKD200-500**			
Discretization interval Δ*t*, sec	0.05			0.2			
Number of sections *n*	3			4			
Measured section length *l*, m	1.5			6.0	7.5		
Time of passing a measured section length t_j, min	0.400	0.330	0.283	1.500	1.800	1.700	1.180
Axis velocity V_n, m/min	3.75	4.50	5.30	4.00	4.20	4.40	6.40
The value of the electric motor off-load current according to the experimental data $I_{\text{хол.ход}}$, A	45			65			
The average value (for the measuring period) of the current of the leading operating device motor $I_{\text{ср.опер}}$, A	73.6	129.5	114.2	166.1	190.1	183.2	190.9
The average value (for the measuring period) of the current of the lagging operating device motor $I_{\text{ср.отст}}$, A	50.1	64.0	57.9	7.9	10.1	9.3	7.3

According to [41], the load on the shearer operating devices is determined taking into account the coal cuttability. Therefore, hardness factors of a rock mass to be broken down (cut) were brought to $\overline{A}_p$ value based on the data presented in [1, 37].

The weighted average value of coal cuttability when cutting by each k-th operating device, kN/m,

$$\overline{A}_{\text{р},k} = \frac{\sum_{i=1}^{m_k} \overline{A}_i H_i}{H_{k.\text{ио}}},$$

where $\overline{A}_i$, H_i – coal cuttability and thickness of the i-th member of rock mass cut by the k-th auger operating device;

$H_{k.\text{ио}}$ – the extracted thickness of rock mass cut by the k-th auger;

m_k – the number of members cut by the k-th auger operating device.

In the course of experimental studies of the shearer operation, the average current values of the electric motors of each shearer cutting drive in increments Δt were recorded using a multichannel energy quality recorder-analyzer [38]. The face was conditionally divided into n sections differing in length l m. At the same time, the time of the passage of each section t_j was recorded, sec ($j = 1..n$).

As an example, Figure 2 shows a fragment of recording the values of the UKD400 shearer auger operating device drive currents when passing a face section 1.5 m long at a speed of 4.5 m/min.

The results of preliminary processing of the experimental research data are given in Table 2.

Shearers of a new technical level have an individual motor for each operating device drive. Then, according to the methodology proposed in [39], the actual value of the power of cutting and loading of rock mass on each k-th operating device drive motor can be determined from the expression, kW:

$$P_k = P_{\text{ном}} \frac{I_{\text{ср}.k} - I_{\text{хол.ход}}}{I_{\text{ном}}} \cos\varphi .$$

According to the operating conditions of shearers with auger operating device for thin shallow seams, the leading auger cuts a coal member adjacent to the seam bottom and loads the broken-down mass, while the lagging auger performs mainly the function of cutting the remaining coal member (Fig. 1). With this in mind, the value of the cutting power on the leading auger $P_{\text{рез.опер}}$ can be determined based on the power values on the lagging auger $P_{\text{отст.}}$ taking into account cutting the coal mass of different average coal cuttability, the factors of coverage of auger face and decreasing stability of the coal mass, kW:

$$P_{\text{рез.опер}} = \frac{P_{\text{отст.}} \overline{A}_{\text{р.отст.ио}}}{k_{\text{осл}} k_{\gamma.\text{охв}} \overline{A}_{\text{р.опер.ио}}},$$

where $k_{\text{осл}}$ – factor of decreasing stability of coal mass; $k_{\gamma.\text{охв}}$ – factor of coverage of auger face.

Then the value of the loading power on the leading operating device $P_{\text{погр.опер}}$ can be found from the expression, kW:

$$P_{\text{погр.опер}} = P_{\text{опер}} - P_{\text{рез.опер}},$$

Determining the value of specific energy consumption requires determining the actual productivity on the extraction for the period under consideration. The performance of the k-th operating device can be determined from the expression, t/min:

$$Q_k = H_{k.\text{ио}} B_{\text{з}} V_{\text{п}} \rho ,$$

where $B_{\text{з}}$ – cut width of the shearer operating device, m;

$V_п$ – axis velocity of the shearer, m/min;

ρ – coal density, t/m^3.

With this in mind, the value of specific energy consumption at the *k*-th auger can be determined as, kWh/t:

$$W_k = \frac{P_{ном}(I_{ср.k} - I_{хол.ход})\cos\varphi}{60 I_{ном} H_{k.ио} B_з V_п \rho}.$$

Based on the above-mentioned features of the modern shearer operation flow sheet for extracting thin seams, the cutting specific energy consumption at the lagging auger can be determined as, kWh/t,

$$W_{разр} = \frac{W_{отст}\bar{A}_{р.отст.ио}}{k_{y.охв} k_{осл} \bar{A}_{р.опер.ио}},$$

and the cutting specific energy consumption at the leading auger $W_{погр}$ can be determined as, kWh/t,

$$W_{погр} = W_{опер} - W_{разр} = \frac{P_{погр.опер}}{Q_{опер}\cdot 60}.$$

The performance parameters of the UKD400 and UKD200-500 shearers obtained based on processing of the experimental study data are given in Table 3.

Based on the data presented in Table 3 regression equations were obtained for determining the power for loading ($R^2{}_{Pпог} = 0.91$) of the studied shearers, kW:

$$P_{пог}(V_п, B_з) = 3{,}612\, B_з e^{0{,}619 B_з V_п}.$$

A plot of power and specific energy consumption for loading as function of operating device effective width and axis velocity of the shearers under consideration is presented in Fig. 3.

The analysis of the given dependences (Fig. 3) shows that the loading power and specific energy consumption increase with increasing the auger effective width in line with increasing the shearer axis velocity: the higher the velocity, the higher the power and specific energy consumption. For instance, at $V_n = 4$ m/min, increasing the auger effective width of the executive body from 0.7 to 0.8 m leads to increasing the power from 14 to 21 kW, i.e. 1.5 times, and the loading specific energy consumption from 0.07 to 0.09 kWh/ t, i.e. 1.3 times. Achieving the axis velocity of $V_n = 6$ m/min leads to increasing the power from 34 to 56 kW, i.e. 1.7 times, and the loading specific energy consumption from 0.11 to 0.16 kWh/t, i.e. 1.5 times. This is due to the beginning of the process of loose rock mass circulation, and the larger the auger effective width, the more intensive the circulation process, and at the lower axis velocity of the shearer the process starts.

Table 3

The findings of processing of the experimental data on UKD400 and UKD200-500 shearers operation

Parameter	Shearer type						
	UKD400			UKD200-500			
Axis velocity, m/min	3.75	4.5	5.3	4.0	4.2	4.4	6.4
Productivity, t/min:							
leading auger	3.307	3.969	4.675	4.032	4.234	4.435	6.451
lagging auger	1.139	1.367	1.61	0.672	0.706	0.739	1.075
Specific energy consumption, kWh/t:							
leading auger	0.187	0.461	0.320	0.593	0.699	0.63	0.462
lagging auger	0.125	0.390	0.227	0.506	0.613	0.537	0.290
for rock mass loading	0.062	0.071	0.093	0.087	0.086	0.093	0.172
Power for loading, kW	12.28	16.73	26.19	21.14	21.92	24.77	66.39

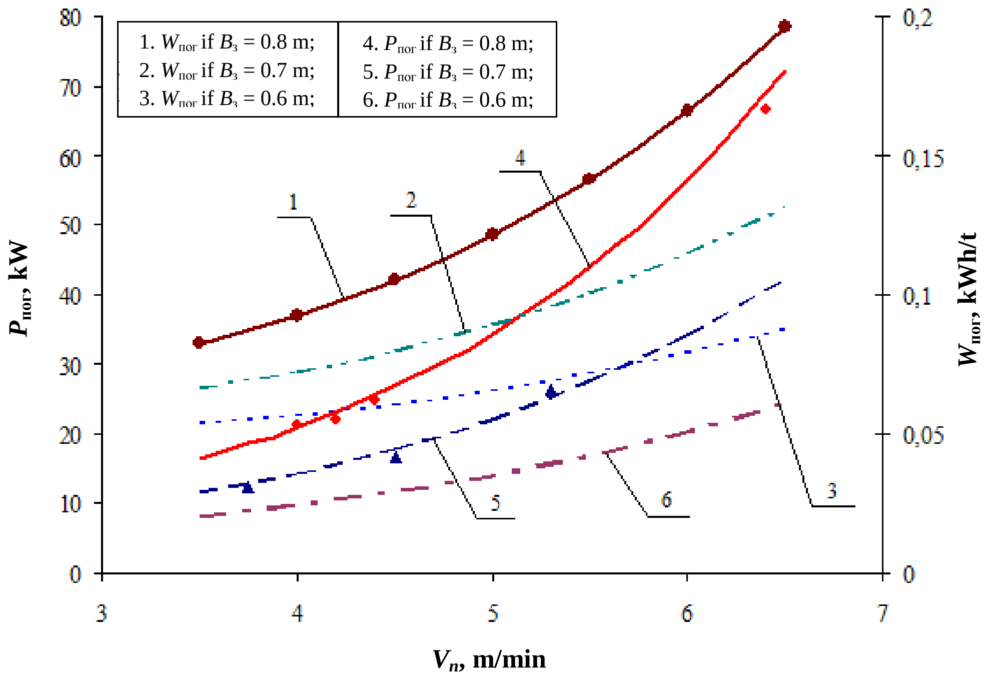

Fig. 3. Plot of power and specific energy consumption for loading as function of operating device effective width and feed rate

To assess the effect of the auger operating device effective width on the efficiency of the shearer operation in thin seams, a nomogram was built based on the proposed methodology [39] (Fig. 4). The nomogram was built for the following mining & geological and geotechnical conditions: the average thickness of the extracted seam of 1.0 m; the longwall face 200 m long; density of the coal to be cut of 1.41 t/m^3; coal cuttability in an uncompressed mass of 220 kN/m; the seam brittleness factor when cutting of 1.65. Arrangement of the cutter set of UKD200-500 shearer was adopted and adjusted taking into account the effective width.

Figure 4 presents the graphs of following dependencies: cutting and loading power of the leading auger operating device P, obtained using the regression dependencies for loading and [40] for cutting, versus the axis velocity (V_n); the specific energy consumption for cutting and loading at the leading auger operating device W, defined as the ratio of the cutting and loading power on the leading auger to its theoretical productivity, versus the axis velocity (V_n); the technical performance $Q_{тех}$ versus the axis velocity (V_n).

Based on the analysis of a new-level shearer fleet designed for coal extraction from thin gently sloping seams, the cutting drive power is at the level of 200 kW, that, taking into account the efficiency of the auger operating device drive gear unit, means about 160 kW at the auger.

Based on the adopted power value at the shearer auger operating device, using the nomogram enabled determining the optimal values of the auger effective width, which are in the range of 0.6–0.7 m, providing maximum performance with minimal specific energy consumption (compared to larger effective values, decreasing the specific energy consumption is about 15–30 %).

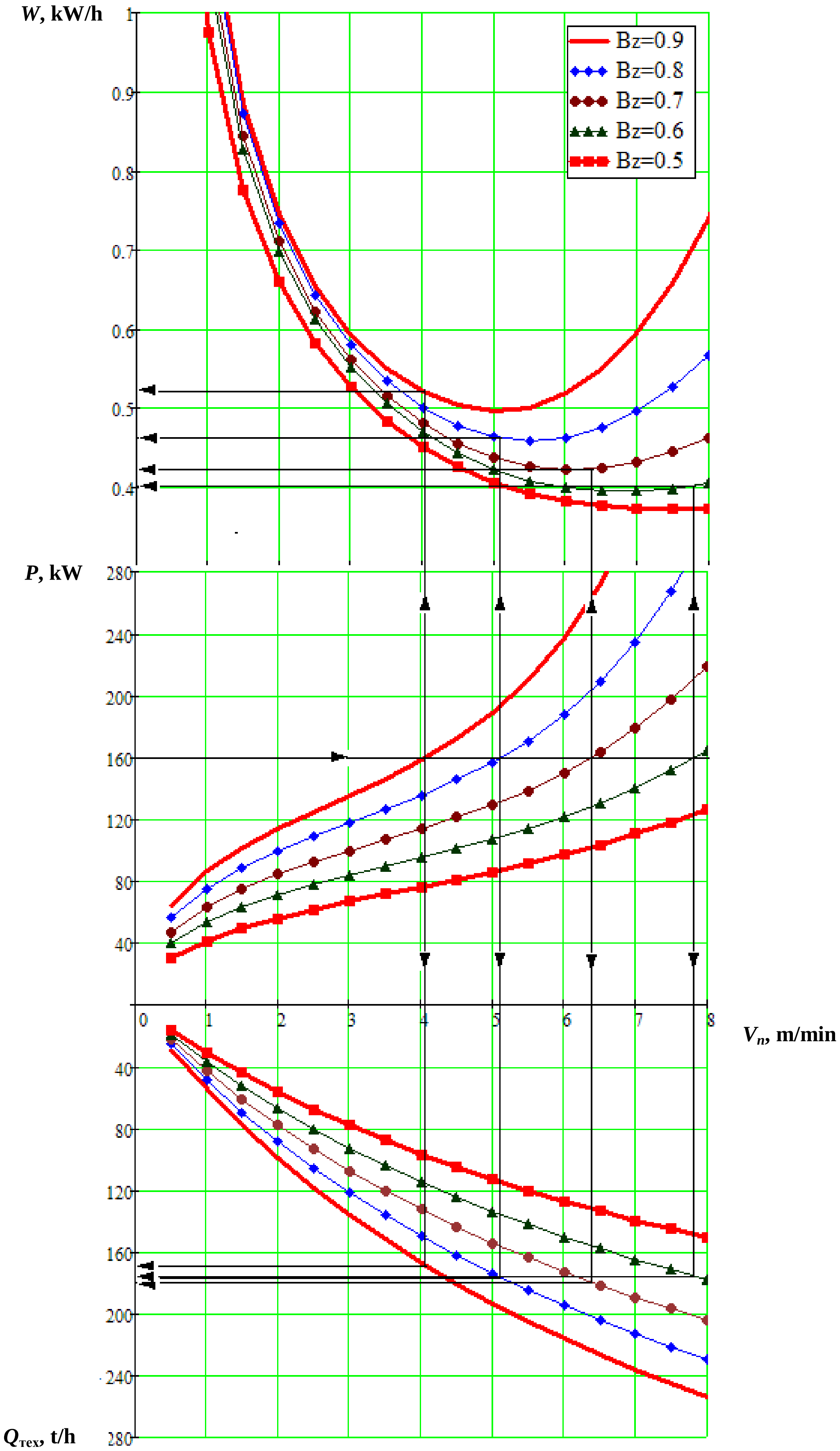

Fig. 4. The findings of processing of the experimental data on UKD400 and UKD200-500 shearers operation

Thus, it seems expedient to determine the optimal values of the auger effective width based on the criterion of the minimum energy parameters of a shearer operation for specific mining & geological and geotechnical conditions, that will significantly improve the efficiency of shearer with the auger operating device operation for extracting thin gently sloping seams, taking into account possible limiting factors for shearer travel speed.

Conclusions and direction of further research

1. An adaptive method for specific mining and geological operating conditions is proposed for determining the specific energy consumption of shearers on cutting and loading for thin seams in actual operating conditions based on fixing the values of currents of the cutting drive motors.

2. Processing of the experimental study data on the operation of UKD400 and UKD200-500 shearers in representative conditions enabled obtaining a dependence of the form $P_{\text{пог}}(V_{\text{п}}, \text{В}_3) = 3.612 \cdot \text{В}_3 \cdot e^{0.619 \cdot \text{В}_3 \cdot V_{\text{п}}}$ of the power for rock mass loading on the axis velocity and the effective width of the operating device. Increasing the auger effective width leads to increasing the loading power and specific energy consumption. In this case the higher the shearer axis velocity, the greater the growth of the loading power and specific energy consumption. This is due to beginning of the process of loose rock mass circulation, and the larger the auger effective width, the more intensive the circulation process and the lower the shearer axis velocity at which the process starts.

3. It was found that the specific energy consumption for coal cutting and loading by the auger operating device can be significantly reduced by selecting a rational auger effective width for the mining & geological and geotectnical conditions under consideration, while maintaining the preset technical performance.

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