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Technical and technological aspects of the coal mine closure based on the geomechanical component assessment

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Abstract

Purpose. Development of a comprehensive methodology for assessing the state of mine workings based on the analysis of their contour displacement patterns when solving the problem of minimizing the risks during the closure of coal mines in Ukraine.

Methods. Based on an integrated analysis of international and domestic trends when assessing the consequences of mine closure, the main provisions of using the method of instrumental mine observations have been substantiated. When solving the problem, the approaches of regulatory documents are taken into account to identify the geomechanical situation according to two conditions: the structure and strength properties of the lithotypes in the adjacent coal-bearing stratum and the peculiarities of the rheological processes manifestation during the development of its displacements.

Findings. The geomechanical, technological and hydrogeological factors have been distinguished that are required to take into account when closing the coal mines. Fundamental methodological provisions have been substantiated for the most reliable assessment of the mine workings state, taking into account the long period of their operation. A criterion for making a decision on the decommissioning of mine workings or their further maintenance is presented.

Originality. A series of generalizing dependences of the mine working contour displacement development has been obtained, which can be divided into four main groups according to the criteria of the structural and strength properties of lithotypes in the adjacent mass, as well as the type of their rheological manifestations: decaying and persistent deformation creep. For each group, using the methods of correlation-dispersive analysis, empirical formulas have been determined for calculating the convergence of the roof and bottom of mine workings, as well as their sides, depending on the geomechanical criterion H/R of the maintenance conditions and the duration t of this period.

Practical implications. The obtained correlation ratios make it possible to predict the residual section of mine working at any time of its maintenance. They are a geomechanical component of its operational state assessment. The result of this research is the development of a new methodology for assessing the mine working state according to the patterns for predicting its contour displacement.

Keywords: *mine, coal, mine working, displacements, rocks*

1. Introduction

Analysing Ukrainian and global trends in coal mining, it should be noted that according to the Global Energy Statistical Yearbook, China produced 3.692 billion tons of coal in 2019 [1]. Other leading coal-producing countries are characterized by the following indexes [1]. The Republic of South Africa has 122 mines with a total production of 264 million tons of coal mined in 2019; almost a quarter of this volume is exported, and in South Africa itself, about three quarters of its energy requirements are covered by coal. In India, 476 mines produced 745 million tons in 2019, while in Turkey approximately the same number of mines produced only 84 million tons. In this sense, it is significant that there are only 46 mines in the United States, which in 2019 produced 640 million tons of coal, and in Indonesia, 5 mines, including open cuts, produced 585 million tons. There are 94 mines operating in Australia, which produced 500 million tons of coal, while in Russia – 187 mines, which produced 425 million tons. In Kazakhstan, 100 mines have a total production of 117 million tons (Fig. 1).

When summarizing the coal production in the above and other countries, its dynamics can be predicted as positive until 2040 and this trend is confirmed by the estimate of the International Energy Agency [2]:

– global coal production in 2040 will amount to 9.23 billion tons;

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– the total share of China, India and Australia in global coal production will amount to 64%;

– stable growth in coal production is predicted in India – an average +100 million tons every 5 years.

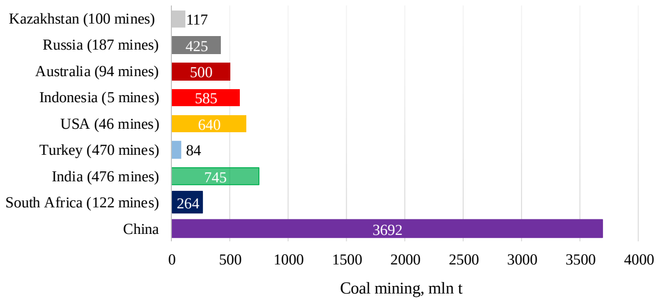

Figure 1. The main trends in global coal mining

The indicated trends in the growth of coal production are stimulated by an increase in the price for this type of mineral. For example, according to the International Energy Agency, to date it has reached an average of $112.2 per 1 ton, which increases the possibility of using innovative coal mining technologies to reduce the producing cost of the final product.

As for Ukraine, there are 146 mines operating in the country now, of which: 67 – on the uncontrolled territory, 33 – state-owned, 46 – privately-owned. In 2019, according to the Global Energy Statistical Yearbook, only 27 million tons of coal have been mined in Ukrainian mines – these figures are self-explanatory. Nevertheless, despite the low production volumes, the role of coal in electrical energy generation will remain significant in the near future [3]-[8]. Thus, the energy strategy in the medium-term perspective retains a significant role of coal in the total volume of primary energy supply: 16.1% – to 2025 and 14.3% – to 2030 [9]. Currently, more than 30% of electrical energy is produced from coal in Ukraine, which means that annually thermal power plants need about 30 million tons with an increase in the demand for coal of rank DG [10], [11].

2. General statement of the problem

For a complete disclosure of contradictions in Ukrainian coal production, let us turn to the socio-economic issues of the industry state [12], [13].

In the spring of 2020, the Ministry of Energy announced that it would not close unprofitable mines yet, and this decision could be continued in 2021. At the same time, a decision will be made on the possible sale of some state-owned mines. On the other hand, for the last two years, the state budget has not provided funds for state support of coal mining enterprises.

In the 2015, UAH 1.1 billion from the state budget was allocated for the restructuring the coal industry, but for the next two years the amount has decreased sharply: UAH 305.6 million in 2016 and UAH 568.1 million in 2017. In the budget of 2018, UAH 1.3 billion was allocated for restructuring, in 2019 – UAH 2.6 billion, and in 2020 – UAH 3.6 billion. In addition, over the past three years, funds have been allocated for the liquidation of unpromising coal mining enterprises.

The other side of electrical energy generation is conditioned by alternative energy sources, which are developing rapidly, but the traditional coal production still remains relevant throughout the world. Nevertheless, there is a steady trend towards the closure of coal mining enterprises. And in this regard, the experience of closing the mines in Europe is very useful.

Coal has played a huge role in the creation of German economic power. However, since the late 1950s, German coal began to lose in price to imported, as well as to other energy carriers, which has led to the beginning of a crisis in the industry. From 1960 to 2000, the number of mines has decreased from 146 to 12. Over the past years, only 2 mines have operated in the country with a total annual production of about 4 million tons.

In Germany, the described processes of the past years are quite similar to the current ones in Ukraine. But, in 2007, the Bundestag decided to withdraw from the costly industry, having planned to complete the process in 2018.

The reduction in coal consumption is also relevant to power plants, which currently have an aggregate capacity of 21 GW, which accounts for 13% of the total electrical energy generation. According to the law-in-draft, the last coal-fired power plant must be removed from the grid not later than 2038. For this purpose, it is necessary to allocate a total of up to 40 billion euros to the Rhine mining region and especially to the East Germany regions to conduct structural changes.

In this regard, it should be noted that "clean" energy already provides 38% of the gross annual energy consumption in Germany. To date, the total consumption of renewable energy in Germany has amounted to about 230 billion kWh, of which 46 billion kWh comes from the solar power plants, 94 billion kWh – from wind and 52 billion kWh – from plants that consume biofuel.

Taking a similar position, the British government has decided to close all coal-fired power plants by 2025. Summing up, it can be argued that in the long term and taking into account the growing global combating climate warming, a decrease in global coal consumption or even a cessation of its production (especially, expensive underground mining) is simply inevitable.

Another reason – environmental. Coal combustion is considered one of the main reasons for the emission of large carbon dioxide amounts into the atmosphere, which causes the "greenhouse effect" and, consequently, global warming [14]-[17]. Therefore, various specific measures are being taken in Western Europe to accelerate the phase-out of coal consumption. Both in Germany and in the UK, this is facilitated by the rapid development of renewable energy sector.

In Ukraine, it is also planned to develop a systematic approach to decision-making on mine liquidation. For example, the decision to close the M.I. Stashkova Mine of DTEK Pavlohradvuhillia PRJSC was influenced by the technical-and-economic performance of the mine. Also, until 2023, the Blahodatna, Stepova, Samarska and Yuvileina mines will be closed.

To close mines in the Central region of Donbas [18], it is necessary to develop a hydrogeological and socio-economic prediction for the region, substantiate the phased mine closure, linking it with funding opportunities, as well as improve the legal/regulatory framework and study environmental problems:

– the development of the earth's surface deformation caused by the water flood of previously drained rocks in the process of mine operational activity and, as a consequence, a decrease in their strength;

– activated rock displacement process with complete water flooding of mine workings and, as a result, the formation of sinkholes, funnels, rock-slides;

– underflooding and overflow of undermined areas;

– contamination of groundwater and surface water, including those used for drinking water supply;
– salinization and pollution of agricultural land soils;
– squeezing-out mine gases onto the daylight surface.

Mine closure is a lengthy process, requiring assessment of all emerging risks. All risks are interconnected and therefore an integrated approach is needed to minimize them. Firstly, it is necessary to determine what causes the risks. Secondly, it is necessary to develop measures to prevent or minimize their occurrence.

The problems arising from the closure of coal mines are that the risks of adverse environmental, social, legislative, financial and technical consequences increase significantly. It is generally accepted that a structured consideration of mine closure risks should be part of the design and planning of mine operations.

However, this paper focuses on taking into account the geomechanical factor within the framework of an integrated approach to the closure of coal mines. Predicting the state of mine workings on the basis of existing regulatory-technical documentation and the study of geomechanical processes is of particular relevance. The main peculiarity of a reliable assessment of the mine working state is taking into account the period of its maintenance, during which there is a displacement development of varying intensity in the surrounding coal-bearing mass. And it is this peculiarity that determines the technical decision on the need (or absence) of the decommissioning of mine working [19].

In this regard, it is relevant to study a methodology that provides for predicting the development of rock pressure manifestations. The methodology [20] is based on the generalization of the results of mine instrumental observations and can easily be corrected by adding new data. It should be noted here that taking into account the current situation with the closure of many mines, as well as other mines located in the temporarily occupied Donbas territory, the range of changes in mining-and-geological conditions has been significantly reduced and may be limited to rocks of low and medium hardness, especially taking into account the influence of weakening factors.

Thus, the task of minimizing the risks of closing coal mines in Ukraine in terms of geomechanical, technological and hydrogeological factors and, based on the determined patterns of rock pressure manifestations, the process of mine water desalination and hydraulic regimes of water inflows, is relevant.

The solution to the above issues is based on the use of the patterns for the long-term development of rock pressure manifestations with the phased decommissioning of mine workings, the peculiarities of the mine water desalination technology, as well as regulation of water inflow into them to limit the negative consequences of the coal mine closure.

To more visually represent the essence and interrelation of the tasks to be solved, an algorithm for their complex implementation has been developed, presented by the structural and logical diagram in Figure 2.

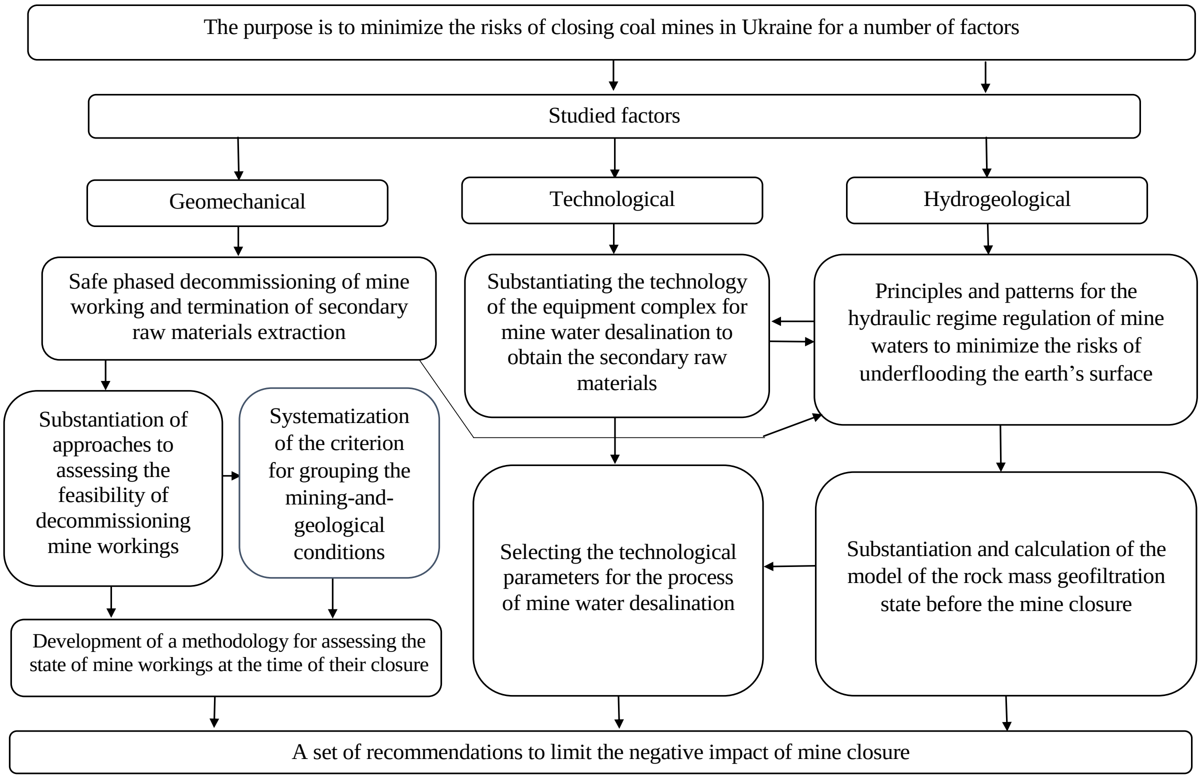

Figure 2. Structural and logical diagram of research

3. Basic research material

Analysing domestic and global trends in coal mining, it should be concluded that it is expedient to apply the main provisions of the methodology for assessing the mine working state and resolving the issue of its decommissioning. Thus, it is planned to use the experimental method of mine instrumental observations of the development of mine working contour displacements and deformations of its support in combination with the methods of correlation-dispersive analysis of the experimental data results [21]-[23].

The basic provisions of the methodological approach to predicting displacements U of the mine working contour (in the roof – the index is "R", in the bottom – the index "B" and in the sides – the index "s") are to determine the relationship between the parameter U and the main geomechanical factors: H – mine working depth; R – weighted-average calculated compressive resistance of lithotypes adjacent to mine working.

From the point of view of existing ideas [24]-[28] about the patterns of increase and stabilization of rock pressure manifestations in a mine working that is outside the zone of stopes influence, the methodological approach [20] is qualitatively consistent with the accumulated experience of maintaining mine workings. However, there are some comments in terms of the accepted idealization of link patterns between U and t.

Firstly, the growth of displacements does not begin from the zero point of time ($t = 0$), and the initial displacements U_i occur conditionally instantaneously approximately with the velocity of propagation of longitudinal vibrations (sound) in the rock [29], [30]. That is, the graphs of the function $U(t)$ growth are depicted from some initial value of U_i [31]. Undoubtedly, the value U_i is affected by the limiting influence of the drifting face, which is confirmed by numerous studies, but, nevertheless, the value U_i is already commensurate with the subsequent development of displacements.

Secondly, the presentation of dependences $U(t)$ in the form of two conjugated line graphs do not quite correspond to the real pattern of growing mine working contour displacements in time. Most of the experimental measurements indicate non-linearity in the growth trends in displacements over time [32]-[36]: in the initial period of maintaining mine working, the growth gradient is higher, and then (with an increase in t) there is a decrease in the rate of increase in U. It can be induced by the cracking of the rock mass and decreasing of its quality [37]. For the sake of objectivity, it should be noted that the bilinear form of the function $U(t)$ in the methodology [20] is designed to partially take into account the indicated pattern of slowing down in time t of the development of mine working contour displacements.

Thirdly, depending on the level of geomechanical indexes H and R influence, these functions $U(t)$ can be divided into two types: first type – the displacements U increase in time t, but with its course there is some stabilization of the process of adjacent mass displacement, at which further growth of U either stops or has very low values (Fig. 3) and the deformation process is caused by the change of geomechanical situation in the rock mass [38], [39]; second type – the displacements U do not stop in time t and later on, some fairly constant growth gradient of U is settled down [31], [40]-[42] (Fig. 4). This geomechanical situation is determined by the rheological property of rocks – deformation creep. In the well-known studies [40], [43], [44] two types of deformation creep are distinguished – steady-state (that is, decaying in time) and unsteady (developing throughout the entire observation period). In this regard, the methodology [20] has been developed taking into account unsteady creep, which is most typical for weakly metamorphosed rocks of the Western Donbas [45].

The approach developed to assessing the mine working state, taking into account the period of its maintenance, is intended to eliminate the noted disadvantages of the methodology [29], but by preserving the fundamental provisions in terms of the main criterion – the contour displacement value – for making a technical decision on the decommissioning of mine working for the entire period of its existence.

Figure 3. Stabilization of the displacement process in the mine working

Figure 4. Settling a constant gradient of displacement growth into mine working

The solution to this problem is based on the determining three groups of time dependences: $U^r(t)$ – displacement of the mine working roof rocks, $U^b(t)$ – its bottom roll, $U^s(t)$ – convergence of the mine working sides.

The methodology is based on the results of mine instrumental observations of rock pressure manifestations. Alongside with it, the state of the fastening structure elements is assessed in terms of the possibility of further performing their functions to ensure the proper mine working stability [39], [46]. It is appropriate to note here that the main difficulty in solving this task is the need to conduct mine observations over a very long period, often calculated in decades [38]. To solve this issue, an original methodology has been developed, based on an integrated study and analysis of the various information sources and discreteness (in time) of mine measurements with their subsequent extrapolation to a longer time frame.

The above statement about the peculiarities and significant difficulties in tracking the state of mine workings over a very long period (or the entire period) of their operation is fundamental in these geomechanical studies and, as mentioned before, represents their novelty. But, this novelty is associated with the formation of an extensive base of initial data, their subsequent systematization and analysis, which requires considerable time. Nevertheless, our research has confirmed the possibility of solving the task, and further on, the algorithm of our actions is explained using specific examples.

The first step involves the selection of mine workings for almost each of the mines that have already been closed or are scheduled for decommissioning in the near future. An obligatory condition for selection is the availability of information at the time of its closure (or during the last mine working survey). Each mine working is characterized by the depth H of placement, texture and properties of adjacent lithotypes, according to which, in compliance with the normative methodology [47], the average compressive resistance R of rocks is calculated and the geomechanical index H/R is determined.

The second step is to gather information on a number of still operating mine workings, including those that are in the stage of construction. In this case, the time frame of maintaining is much shorter and allows to assess the state of mine workings at lower values of t, which provides the ability to set dependences of $U(t)$.

Firstly, some general positions should be noted in terms of the initial conditions: the ranges of the depth variation of mine workings placement H = 200-1000 m and the calculated compressive resistance of the adjacent coal-bearing strata of R = 5-60 MPa are studied, which cover almost the entire interval of geomechanical factors variation. In this case, the "extreme" boundary values of the criterion H/R vary from 3.3 m/MPa to 200 m/MPa and are practically the same both for the Western Donbas and for the Krasnoarmiiskyi coal-bearing region (Ukraine); the most probable range of criterion variation is H/R = 10-50 m/MPa.

Then, the first distinguished textural type of the adjacent coal-bearing strata is studied – the immediate roof and the first layers of the main roof are represented by argillite and siltstones with a total thickness of no more than 5-7 m and a compressive resistance in the sample of no less than $\sigma_{compr} \geq$ 40-50 MPa; above, there is sandstone with a thickness of no less than 3-4 m with a hardness coefficient of at least $f \geq 6$. Most lithotypes are in a naturally moist state with a low intensity of fracturing; they are characterized by moderate rheological properties with decaying creep.

In the absence of the stopes influence, overworking and undermining, the mine workings predominantly retain their operational parameters in compliance with the requirements and standards. The convergence of the roof and the bottom $U^{r,b} \leq$ 400-500 mm, the convergence of the sides $U^s \leq$ 200-250 mm, the section loss $\Delta S/S_{cl} \leq$ 20-25% (here it is designated as S_{cl} – the cross-sectional area of mine working in the clear till subsidence).

Such mining-and-geological conditions ensure a satisfactory operational state of mine workings throughout the entire period of their maintenance. The issue of decommissioning mine workings is not due to geomechanical factors, but by technological and economic aspects of the mine operation.

The second distinguished textural type for the Krasnoarmiiskyi coal-bearing region – is the immediate and main roof at a height of at least 12-15 m, represented by soft and medium hardness argillite and siltstones (f = 3-5), as well as soft sandstone ($f \leq 6$), characterized by a moisture-saturated state and intense fracturing. According to the normative methodology [47], the value of the averaged calculated compressive resistance is R = 5-10 MPa. When the mine workings are placed at a depth of at least 200-250 m, the index H/R is 20-50 m/MPa and more with a corresponding intensification of the rock pressure manifestations. Nevertheless, lithotypes are characterized by creep decaying with time.

It is noted that in mine workings that have been in operation for a long time, the decay of the displacement velocity along their contour is mainly observed with the stabilization of $U^{r,b}(t)$ and $U^s(t)$ values. The time interval t_{st} from the moment of mine working construction to the stabilization of its contour displacements also has a correlative relationship with the geomechanical criterion H/R: the value of t_{st} increases with the deterioration of mining-and-geological conditions, that is, with an increase in the ratio of H/R. This pattern is quantitatively described by the dependences:

– for the convergence of the roof and bottom in mine workings:

$$t_{st}^{r,b} = 236\left[1 - \exp\left(-0.024H / R\right)\right],\ \text{day}; \tag{1}$$

– for convergence of blocks in mine workings:

$$t_{st}^{s} = 187\left[1 - \exp\left(-0.027H / R\right)\right],\ \text{day}. \tag{2}$$

In the mine workings of Western Donbas, the collected amount of experimental data confirms the above-mentioned patterns of the increase in displacements along their contour only in qualitative terms, and in quantitative terms, a number of differences have been revealed. The available peculiarities of $U^{r,b}(t)$ and $U^s(t)$ functions are quite understandable, since the mining-and-geological Western Donbas conditions are distinguished by the occurrence of less hard, more plastic, weakly metamorphosed lithotypes and a slightly shallower depth of mining, mainly up to 500-600 m [48]. Even the hardest lithotypes, such as sandstone and coal, are characterized by a compressive resistance in the sample of mainly $\sigma_{compr} \leq$ 40-50 MPa, and limestone has an insignificant propagation in the form of very thin interlayers, as a rule, less than 0.2-0.3 m thick. Given the widely distributed weakening factors of moisture saturation and fracturing in the coal-bearing strata, the real compressive resistance of lithotypes decrease sharply [49]. To this should be added the pronounced rheological properties of most rocks [24], [29], which in total leads to a decrease in the calculated compressive resistance of the adjacent coal-bearing strata, mainly to R = 5-20 MPa. In such conditions, more intense rock pressure manifestations are quite expected.

Also, in the Western Donbas conditions, two forms of deformation creep, effecting the patterns of displacement development, are actively manifested in two types: first type – with an increase in the period of the mine working maintenance, the displacement velocity decreases to insignificant values and it can be argued about some constancy of values $U^{r,b}(t)$ and $U^s(t)$; this period is called the time t_{st} of the contour displacement stabilization. The second type – with an increase in time t, the displacement velocity decreases, but, as before, remains a significant value with a long period of the mine working maintenance; this type of displacement development is determined by the persistent creep of very soft rocks (mainly argillite) and is largely represented in the methodology [20].

Thus, for the Western Donbas conditions, the main principle of separating the patterns of the displacement development is to take into account the rheological properties of lithotypes of the adjacent coal-bearing strata with a subordinated value of its texture: the predominant occurrence of more stable lithotypes of medium and high thickness with a hardness coefficient of f = 2-5 (sandstones and coal seams are mainly in a moisture-saturated state, exposed to moderate and intense fracturing, and argillite and siltstones are predominantly in a naturally moist state with weak and moderate fracturing) contributes to decay of the deformation creep process and stabilization of contour displacements at some relatively constant level; the predominant occurrence of very soft and moisture-saturated fractured argillite and thin- and medium-bedded siltstones provokes persistent deformation creep and a constant increase in displacements of the mine working contour over a very long period of its maintenance.

The second type of patterns $U(t)$ in the displacement development of the mine working contour in time t is conditioned by the occurrence in the adjacent coal-bearing strata of a part of the lithotypes, which are characterized (taking into account the weakening factors influence) by persistent deformation creep. The convergence of the roof and bottom, as well as the sides of mine working, takes years, and over a long period of the mine working maintenance, they accumulate, and their total values can no longer be neglected.

It should be underlined that even proper geological research and wide geomechanical invetsigations can lead to different conclusions due to another statistical approach to the collected data [50]. So the average values taken to the analyses should be consider carefully, as the variation of the rock compressive strength R can reach even 40% [50].

This development is based on the results of the research performed with partial use of the methodological principles for predicting the rock pressure manifestations in regulatory documents [47], [20]. The methodology makes it possible to assess the state of mine workings operated for a long period, taking into account the factor of the displacement development of the adjacent coal-bearing mass in time.

4. Results and discussion

The procedure for calculating the parameters of the rock pressure manifestations for the prospect of further operation of mine working:

1. The predicted parameters of convergence of the roof and bottom $V^{r,b}(t)$, sides $U^s(t)$ of mine working and its residual section $S_{res}(t)$ over the time t of maintenance are determined depending on the geomechanical index H/R, which is the ratio of the mine working depth H to the calculated compressive resistance value R of rocks in the adjacent coal-bearing strata. Parameters H and R are determined according to the data of mining-and-geological prediction using the calculated provisions of the normative methodology [47].

2. The contour displacement of mine workings is calculated taking into account the separation of the conditions for their maintenance in the two studied coal-bearing regions and the rheological properties of lithotypes of the adjacent coal-bearing strata.

3. For the Krasnoarmiiskyi coal-bearing region, the problematic conditions for maintaining mine workings are characterized as follows. All lithotypes have the rheological property of deformation creep loading which decays in time; in terms of strength properties, the adjacent mass is represented by soft and medium hardness argillite and siltstones $f \leq$ 3-5, as well as soft sandstone $f \leq 6$. Taking into account the influencing factors of moisture saturation and fracturing that weaken the rock, there is a high probability of intense rock pressure manifestations, especially with a long period of the mine workings maintenance, which actualizes the issue of their further operation.

The convergence of the roof and bottom $U_l^{r,b}$, as well as the sides U_l^s of mine workings during a long period of their operation for given mining-and-geological conditions is determined by Formulas (3) and (4):

$$U_l^{r,b} = 8.45(H/R)^{1.4}, \quad \text{m}U_{\text{дл}}^{\text{к,п}} = 8{,}45\left(\frac{H}{R}\right)^{1.4}, \text{ММ}\text{m}; \tag{3}$$

$$U_l^s = 3.1(H/R)^{1.35}, \text{ mm.} \tag{4}$$

The residual cross-sectional area of mine workings is calculated by the formula:

$$S_{res} = S_{cl} - \Delta S, \tag{5}$$

where:

S_{cl} – the cross-sectional area of mine working in the clear till subsidence;

ΔS – the loss of the cross-sectional area of mine working during the period of its operation:

$$\Delta S = U_l^{r,b}\left(0.9B_w - U_l^s\right) + U_l^s h_w, \tag{6}$$

where:

B_w and h_w – initial width and height of mine working.

4. For the Western Donbas mining-and-geological conditions, with the occurrence of adjacent lithotypes with decaying deformation creep at a hardness coefficient of f = 2-5, with rock layers predominantly with medium and high thickness, which are mostly water-free (with the exception of sandstone and coal seams) and moderately fractured, displacements of the mine working contour are determined by the Formulas (7) and (8), and the residual cross-sectional area – by the Formulas (5) and (6):

$$U_l^{r,b} = 5.87(H/R)^{1.6}, \text{ mm;} \tag{7}$$

$$U_l^s = 4.31(H/R)^{1.5}, \text{ mm.} \tag{8}$$

5. The conditions for maintaining mine workings in the Western Donbas are characterized by the predominant occurrence in the adjacent coal-bearing strata of lithotypes with persistent deformation creep; moisture-saturated and intensely fractured argillite and siltstones are positioned as very soft rocks, their texture is mainly thin and medium-bedded. Taken together, these factors contribute to the active development of rock pressure manifestations over a very long period of mine workings maintenance.

The dependences of the increase in the convergence of the roof and bottom $U^{r,b}(t)$, as well as the sides $U^s(t)$ in time t is determined by Formulas (9) and (10), and the value of the residual cross-sectional area constantly decreases and is calculated by the same Expressions (5) and (6) by substituting values $U^{r,b}(t)$ and $U^s(t)$ in them for the corresponding period t of mine working maintenance:

$$U^{r,b}(t) = 5.33(H/R)^{1.7} + (0.55H/R - 0.8)(t-12), \text{ mm;} \tag{9}$$

$$U^s(t) = 5.0(H/R)^{1.55} + (0.28H/R + 2.7)(t-12), \text{ mm.} \tag{10}$$

It is worth mentioning another rock mass behavior and convergence tendency if the floor rocks are waterlogged, what was investigated in the paper [51].

6. The given calculation expressions make it possible to assess the mine working state in terms of the patterns of the geomechanical factor influence on making the technical decision on the feasibility of its further operation.

5. Conclusions

Analysis of the current normative methodologies and developments for predicting the parameters of the rock pressure manifestations in mine workings, maintained outside the zone of stope operations influence in conditions of weakly metamorphosed rocks and those close to them, makes it possible to substantiate the fundamental methodological provisions for the most reliable assessment of the mine workings state, taking into account the long period of its operation.

The new methodology is based on the generalized results of mine instrumental observations, taking into account the approaches of existing regulatory documents by means of dividing the geomechanical situation according to two conditions: texture and strength properties of lithotypes in the adjacent coal-bearing strata; peculiarities of the rheological process manifestations of its displacement development into the mine working cavity.

A series of generalizing dependences of the mine working contour displacement development have been obtained, which can be divided into four main groups according to the criteria of the textural and strength properties of lithotypes in the adjacent mass, as well as the type of their rheological manifestations: decaying and persistent deformation creep. For each group, using the methods of correlation-dispersive analysis, empirical formulas have been determined for calculating the convergence of the roof and bottom of mine workings, as well as their sides, depending on the geomechanical criterion H/R of the maintenance conditions and the duration t of this period.

The practical result of the research performed is a new methodology for assessing the mine working state according to the patterns of predicting the displacement of its contour. The revealed correlation ratios make it possible to promptly predict the residual section of mine working at any time of its maintenance, which forms the geomechanical component of its operational state assessment for making a decision on its decommissioning or further maintenance.

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Техніко-технологічні аспекти припинення діяльності вугільної шахти на базі оцінки геомеханічної складової

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Мета. Створити комплексну методику оцінки стану виробок на базі аналізу закономірностей зсуву її контуру при вирішенні задачі мінімізації ризиків при закритті вугільних шахт України.

Методика. На базі комплексного аналізу світових і вітчизняних тенденцій при оцінці наслідків закриття шахт обґрунтовано основні положення використання методу інструментальних шахтних спостережень. При вирішенні задачі враховуються підходи нормативних документів при поділі геомеханічної ситуації за двома умовами: текстура та властивості міцності літотипів прилеглої вуглевмісні товщі та особливості проявів реологічних процесів розвитку її зрушень.

Результати. Виділено геомеханічні, технологічні та гідрогеологічні фактори, які є обов'язковими до врахування при закритті вугільних шахт. Обґрунтовано принципові методичні положення з найбільш достовірної оцінки стану виробок з урахуванням тривалого періоду їх експлуатації. Наведено критерій для прийняття рішення погашення виробок або їх подальшої підтримки.

Наукова новизна. Отримано сім'ю узагальнюючих залежностей розвитку зсуву контуру виробки, які виділено в чотири основні групи за критеріями текстури і міцнісних властивостей літотипів прилеглого масиву, а також виду їх реологічних проявів: згасаюча і незгасаюча повзучість деформацій. Для кожної групи за допомогою методів кореляційно-дисперсійного аналізу встановлено емпіричні формули для розрахунку зближень покрівлі й підошви виробок, їх боків, залежно від геомеханічного критерію H/R умов підтримки і тривалості t цього періоду.

Практична значимість. Отримані кореляційні співвідношення дозволяють прогнозувати залишковий переріз виробки в будь-який момент часу її підтримки. Вони є геомеханічною складовою оцінки експлуатаційного стану виробки. Результатом цих досліджень стало створення нової методики оцінки стану виробки по закономірностям прогнозу зміщення її контуру.

Ключові слова: *шахта, вугілля, гірнича виробка, зміщення, породи*

Технико-технологические аспекты прекращения деятельности угольной шахты на базе оценки гемеханической составляющей

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Цель. Создать комплексную методику оценки состояния выработок на базе анализа закономерностей смещения ее контура при решении задачи минимизации рисков при закрытии угольных шахт Украины.

Методика. На базе комплексного анализа мировых и отечественных тенденций при оценке последствий закрытия шахт обоснованы основные положения использования метода инструментальных шахтных наблюдений. При решении задачи учитываются подходы нормативных документов при разделении геомеханической ситуации по двум условиям: текстура и прочностные свойства литотипов близлежащей углевмещающей толщи и особенности проявлений реологических процессов развития ее сдвижений.

Результаты. Выделены геомеханические, технологические и гидрогеологические факторы, которые обязательны к учету при закрытии угольных шахт. Обоснованы принципиальные методические положения по наиболее достоверной оценке состояния выработок с учетом длительного периода их эксплуатации. Представлен критерий для принятия решения погашения выработок или их дальнейшего поддержания.

Научная новизна. Получены семейства обобщающих зависимостей развития смещений контура выработки, выделенные в четыре основные группы по критериям текстуры и прочностных свойств литотипов близлежащего массива, а также виду их реологических проявлений: затухающая и незатухающая ползучесть деформаций. Для каждой группы с помощью методов корреляционно-дисперсионного анализа установлены эмпирические формулы для расчета сближений кровли и почвы выработок, их боков, в зависимости от геомеханического критерия H/R условий поддержания и длительности t этого периода.

Практическая значимость. Полученные корреляционные соотношения позволяют прогнозировать остаточное сечение выработки в любой момент времени ее поддержания. Они являются геомеханической составляющей оценки эксплуатационного состояния выработки. Результатом этих исследований явилось создание новой методики оценки состояния выработки по закономерностям прогноза смещения ее контура.

Ключевые слова: *шахта, уголь, горная выработка, смещения, породы*