Study results on geotechnological processes of mining flat thick coal seams with top-coal drawing in face 21-1-5 of “Olzherasskaya” mine

V V Senkus and A Yu Ermakov
LLC “Siberian Scientific Research Institute of Coal Processing”, 1 Gornaya Street, Prokopyevsk, 653000, Russia
E-mail: senkusvv@suek.ru

Abstract. In the paper the modes of hydraulic props of powered support are considered; the regularities of their loading are established that allows the powered support for thick flat seams mining with top-coal drawing to be chosen.

1. Introduction
The standard longwall mining technology requires the extraction of the lower seam layer using a mechanized complex and drawing the top-coal (of average thickness 3.7 m) on the goaf conveyer located under the powered support. The length of top-coal draw is 7-8 meters (5 units).

The technological process of coal extraction with top-coal drawing in the longwall face includes the following operations: angle shearing; extraction of the coal “chip”; moving the support units; moving the face conveyor; top-coal drawing; moving the goaf conveyor.

Top-coal is drawn after each pass of the shearer, right after the support units shifting. The process of top-coal drawing onto the goaf conveyer is as follows:
- by the reduction of the telescopic cylinder gate of the tail barrier the top-coal is drawn onto the conveyer;
- by lifting and lowering the tail barrier the additional softening and crushing of the top-coal is achieved, while the coal drawing and loading onto the conveyer take place;
- extension of the gate allows large lumps of coal to be crushed.

If ROM contains up to 30% of rock, the gate is closed and the coal draw is stopped. Large lumps of rock are pushed from the conveyor by the tail barrier. In case of partial coal drawing the unit is moved down two or three times at the height of 200-300 mm and to its maximum setting load for crushing the top coal.

The coal bench is not released at a distance of 5m at the top and bottom parts of the longwall face.

After finishing the top-coal draw operation the goaf conveyer is shifted. The shifting length at one time should not exceed 22.5 m (15 units) and should be less than 7.5 m (5 units).

2. The research results and their analysis
The presence of the ruptured zone and rock-mass weakening in the area of installation chamber caused the smooth roof rock collapse and timely roof coal caving during dismantling the complex from the installation chamber.
During the research into the interaction between the power support units and host rock we used the following evaluation criteria [1]:
- initial setting load, the finite resistance, the speed of hydraulic props reaction to the weights for a cycle;
- specific pressure of the support on the roof and the floor, the pressure of the relief valve action;
- rate of the longwall face supporting;
- ratio of the hydraulic sliding;
- roof lagging ratio;
- maximum distance from the face to the front edge of the flap;
- longitudinal and transverse stability of the support unit.

According to the diagrams of pressure records in the head end of hydraulic props we evaluated the modes of hydraulic props operation. The pressure in hydraulic props was recorded after the shift of the complex from the installation chamber to a distance of 30m. Figure 1 presents an example of the compacted recording diagrams of pressure in the hydraulic prop of the powered support unit at the end of the winning cycle of extraction panel 21-1-5 (unit No. 53, upper front).

![Figure 1](image1.png)

**Figure 1.** The pressure in the hydraulic prop of a powered support unit at the end of the winning cycle of extraction panel 21-1-5 (unit No. 53, upper front): \( P \) – setting load pressure, MPa, \( l \) – longwall length, m.

The pressure diagrams are compacted with the compaction step of 10 m. The pressure axis is divided into six sections vertically with a scale division value of 10 MPa. The pressure of safety valves opening of hydraulic props is approximately 42 MPa. The analysis shows that the roof supports work in the mode of growing resistance. Working in constant resistance mode occurs during the main roof settling.

The diagrams of the hydraulic props pressure serve to identify the areas in the extraction panel with varying intensity of rock pressure.

Figure 2 shows the fragment of the pressure record in the supports before the fall of the main roof rock at a distance of 40-50 m from the installation chamber. The hydraulic props worked in this area in the mode of a setting load. In continuation of the winning cycle the hydraulic props worked without weights. The setting load pressure ensured stable operation of the support units. The setting load value varied from 20 MPa to 25 MPa and reached 47-59% of the safety valve opening pressure (the degree of the support nominal resistance was 47-59%) [58].
Figures 2-3 show the fragment of the pressure recording in the hydraulic props during the main roof settling within the thickness of the active roof.

**Figure 2.** Fragment of the pressure recording in the front upper powered prop before the first roof caving.

**Figure 3.** Fragment of the pressure recording in the front upper powered support. The safety valve release (159-163 m from the installation chamber).

The longwall face shift from the installation chamber was 145-163 m. In this area the support props after having been moved and stressed increased pressure at a high speed and operated in the constant resistance mode. Safety valves trigged, props yield occurred. Safety valves released at a pressure of 42-43MPa. There were no “hard” props fitting.

Face stoppage results in the increased load on the support units. Longwall face 21-1-5 in this area of the panel (463 m from the installation chamber) was in the state of emergency. The props worked for a long time under heavy loads and in the mode of constant resistance. The safety valves opened and closed periodically providing constant resistance to displacing rocks. The value of hydraulic prop reaction was approximately 2000 kN.

During the period following the regular roof settling of the rock pressure is insignificant, the rock displacement is balanced by the props reactions, the value of which is determined by the level of the set load.

During secondary settling, when the rock caving occurs within the thickness of the active roof, the props operate in the mode of constant resistance. The pressure in the props varies from 35 MPa to 43 MPa, the props reaction is 1750-2150 kN. The reaction of the support unit without taking into account the unevenly distributed load between the props is 7000-8600 kN.

The histogram of the distribution of the winning cycle duration is shown in Figure 4.
The pressure of the initial setting load in the head end of hydraulic props varied from 2.5 to 29.5 MPa with an average value 14.33 MPa (Figure 5). Load force varied from 125 kN to 1475 kN with an average value 716-718 kN.

The nominal force value of the initial setting load for hydraulic props of the roof support ZF 8000/22/35 is 1546 kN with the setting load ratio equalling 0.77. The extent to which the initial load can be used by average values is:

\[
\frac{P_{\text{I,mean}}}{P_{\text{I,nom}}} = \frac{716}{1546} = 0.46
\]

The initial load of the support hydraulic props is used only to 46%, while the nominal setting load coefficient is 77% of the nominal props resistance.

**Figure 4.** Distribution of the winning cycle duration of the combine in longwall face 21-1-5.

**Figure 5.** Distribution of the initial setting load of support hydraulic props in longwall face 21-1-5.

Figure 6 presents the histogram of the pressure distribution in the support hydraulic props at the end of the winning cycle, and the actual distribution of the hydraulic prop reaction at the end of the winning cycle is in Figure 7.
According to the measurement results shown in Figures 7-8, it is found out that the final response of hydraulic props as well as the initial setting load vary within a wide range, reaching a nominal value of 1960-2000 kN. The average pressure value in the head end is changed from the value of the initial load to the pressure of the relief valve action (42 MPa). The actual average reaction of a hydraulic prop in the observation period was 1073-1100 kN.

The props reach the nominal resistance, safety valves are activated at a pressure of 42 MPa, but at the average actual reaction the degree of the use of the working (nominal) support resistance does not exceed 55%.
The actual value of the coefficient of the initial setting load at the average value of props reaction 1100 kN and the average value of the initial load 716 kN is 0.65 at the nominal value of 0.77. The results of the performed pressure measurements in the head ends of hydraulic props show that:

- the actual initial setting load is fixed within the range from 2.5 to 29.5 MPa at the average value 14.33 MPa, 46% of the initial load value is used;
- the coefficient of the initial load is 65% and is less than the nominal value of 77%;
- the nominal resistance of the support at use is 55% of the mean value.

\[ \frac{R_{\text{act}}}{R_{\text{nom}}} = \frac{1100}{2000} = 0.55. \]

Figures 8-9 show the pressure distribution histograms in head ends of hydraulic props and the rate of the pressure increase that help to assess the nature and intensity of the support props loading.

\( \text{Figure 8. Variation of the pressure increase in the hydraulic prop per winning cycle.} \)

\( \text{Figure 9. Distribution of pressure increase in the hydraulic prop per winning cycle in longwall face 21-1-5.} \)

The pressure increase in the hydraulic prop was determined by the formula
\[ \Delta P = P_f - P_i \]

where \( P_f \) – the finite pressure in the hydraulic prop per winning cycle; \( P_i \) – pressure of the initial load in the hydraulic prop per the winning cycle.

The analysis of the histogram in Figure 9 shows that the maximum pressure increase was 23 MPa. Basically, the pressure increase varied from 5 MPa to 11 MPa with a mean value 7.06 MPa. Maximum loads occur during the primary and secondary settling of the active roof. The impact of coal draw on the pressure increase in the hydraulic props is not recorded; the main influence on the pressure increase was produced by the coal cutter.

The speed of the pressure increase during the winning cycle was determined by the formula

\[ \dot{P} = \frac{\Delta P}{\tau} = \frac{42 - 14.33}{0.059} = 469 \text{ min}, \]

where \( \tau \) – the duration of the technological coal mining cycle, min.

The rate of pressure increase changes from 0.0076 to 0.14 MPa/min. The average rate of the pressure increase was 0.059 MPa/min. At a mean initial setting load 14.33 MPa the time of reaching the nominal resistance would be

\[ \tau = \frac{P_{\text{nom}} - P_i}{\dot{P}} = \frac{42 - 14.33}{0.059} = 469 \text{ min}, \]

that considerably exceeds the length of the winning cycle (190.6 min). Consequently, according to the mean values the probability of reaching the nominal resistance by the support props is insignificant.

Insignificant pressure rises appear with a high frequency, having no threat to hydraulic props. Pressure rises leading to the nominal resistance in the mode of constant resistance appear at a much slower rate, total pressure in the hydraulic props is not beyond the limits set for pressure relief valve (42-43MPa). The rate of pressure rise is insignificant; safety valves are activated without delay, excluding the “casting” of pressure in the head ends of hydraulic props. The time of reaching the nominal resistance is 85-86 minutes, which is less than the average duration of the technological coal extraction cycle (190.6 min). Consequently, it is possible for the props to work in the constant resistance mode, but the transition to the constant resistance mode is not dangerous, because the rate of pressure increases is negligible (0.14 MPa/min), the safety valves are activated without delay.

It is established that:

- pressure increases in the props are highly frequent, insignificant in value and present no danger for the hydraulic props;
- pressure increases exceeding the nominal value (pressure setting of relief valves) is not observed;
- limit pressures in the hydraulic props causing safety valves activation are improbable.

The number of cycles, in which the safety valves were activated during mining the extraction pillar 21-1-5, amounted to 5.4% of the total winning cycles.

To assess the interaction between powered support units and host rocks it is important to consider the indicator of the uneven distribution of pressure acting on the unit between hydraulic props. Table 1 summarizes the data on the pressure distribution between the unit props in the process of mining the extraction pillar 21-1-5 during the secondary settling of the active seam roof.

The analysis of the data in Table 1 shows that in this sector relatively the same initial load on hydraulic props was set, the ratio of non-uniformity between the face props was 0.97, between the goaf props – 1. The front row props were loaded with an average force of 1041 kN, the back row – 967 kN.
Table 1. The uneven distribution of pressure between the support unit hydraulic props.

|                      | Face Row       | Goaf Row        |
|----------------------|----------------|-----------------|
|                      | Right (low), (MPa) | Left, (MPa) | K_f | Right, (MPa) | Left, (MPa) | K_f |
| Initial Load         | 20.55          | 21.09          | 0.97 | 19.5          | 19.2          | 1   |
|Finite Reaction       |                |                |      |               |               |     |
| Mean Values          | 21.36          | 20.45          | 1.04 | 18.2          | 22.1          | 0.82|
| Maximum Values       | 33             | 36.58          | 0.9  | 34.9          | 35.6          | 0.98|

The reaction of the front (face) hydraulic props by mean values differed little from the reaction of the goaf hydraulic props. In the face row the props reaction was 1068 kN and 1022 kN, the coefficient of variation between the reactions was 1.04, in the goaf row respectively 910 kN and 1105 kN, the coefficient of variation between the props was 0.82. According to the maximum values the reaction of the face row was 1650 kN and 1820 kN, the coefficient of variation – 0.9, the goaf props respectively 1745 kN and 1780 kN, coefficient of variation – 0.98.

The reactions of hydraulic props in the face and goaf rows are not significantly different. The hydraulic props of a support unit are loaded almost similarly.

The evaluation of hydraulic props loading parameters results in the following conclusions:

- powered support parameters are used insufficiently, the initial load – 46% of the nominal, hydraulic props response – 55%;
- the actual initial load ratio is 0.65 at a nominal value of 0.77;
- the support hydraulic props most of the time operate in the mode of the specified load and the growing resistance, without reaching the nominal resistance level.

The constant resistance mode is achieved during periods of primary and secondary settling of the active roof. The share of work of hydraulic props in the constant resistance mode during the extraction pillar mining on the area of 77 0 m was 5.4% of the total winning cycles;

- pressure increases in the support hydraulic props occur smoothly at a low speed. The average rate of pressure increase is 0.059 MPa/min, maximum – 0.14 MPa/min. Sudden roof settlings were not registered, pressure “castings” in the head ends of hydraulic props during transition into the mode of operation with a constant resistance are absent;
- the mean time of achieving constant resistance mode is 469 minutes and is much longer than the average duration of the winning cycle – 190.6 min, there is no possibility for hydraulic props to work with constant resistance.

The time of achieving the constant resistance mode during the regular settlings within the active roof thickness is 86 minutes and is much less than the duration of the winning cycle. The possibility of hydraulic props to operate at a constant resistance is high.

The initial load for the support hydraulic props of the face and goaf rows is specified with the unevenness ratio 0.97-1.0, while the load is distributed uniformly between the hydraulic props, unevenness ratio varies in the range 0.9-0.98. Coal sloughing occurs periodically, mainly during regular periods of active roof settling. The probability of coal sloughing occurrence at various locations along the length of the longwall face is presented as a histogram (Figure 10).

The analysis of the data presented in Figure 10 shows that the coal sloughing in the longwall face appears at the head- and tailgates, in some local areas of the longwall face and along the entire length of the face simultaneously.
The most frequent occurrence of coal sloughing is observed in local areas, the length of local areas of coal sloughing varies from 1 m to 16 m, the mean value of the local area length is 7.8 m (Figure 11). At head- and tailgates the coal sloughing is less common than in the local areas. Coal sloughing over the longwall length occurred during the main roof settling, i.e. coal sloughing is a periodicity function of the roof setttings, it significantly affects geomechanical parameters, reduces the coal strength in the seam edge, displaces the maximum of the bearing pressure deep into the solid. The observations show that the maximum of the bearing pressure is displaced 4.5-8 m deep into the solid from the face line.

![Figure 10. The probability of occurrence of coal sloughing at various locations along the longwall face.](image)

Figure 11. Coal sloughing parameters in longwall face 21-1-5: a – sloughing depth; b – the length of local areas where coal sloughing occurs.
3. Conclusions
The maximum distances from the face edge to the front end of the support vary widely depending on the condition of the face and top-coal. According to the measurements the spacing varied from 0.26 m to 0.42 m, the mean value is 0.4 m.

Coal sloughings and falls from the top-coal through the unit-to-unit gaps occurred mainly during the move of the support units. According to the degree of coal spillage the astel supporting ratio is estimated at the level of 0.9. Unit-to-unit gaps changed in the range from 2 mm to 30 mm, the mean value is 4 mm. It should be noted that these gaps exclude coal spillage in a static state of the support units, the coal spillage occurs when support units are moved. Face protective shields prevent coal falls and sloughings in the face if coal sloughings are not more than 0.3 m. If the coal sloughing value is higher the protective shields are ineffective.

References
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