Shearer mining application to soft thin-seam with hard roof

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Abstract

Study status on shearer mining in thin seams in the world is introduced. Base on the geological conditions of instable and soft thin-seam with hard roof in Caoyao Coal Mine of Yima Coal Group, China, and combined with related parameters of strata behaviors at coal faces, the paper concludes that the strata control on the thin-seam coal face is comparatively easy in line with the criteria for classification on strata stability of gently-inclined coal faces in China. Hydraulic supports of two-prop shielding with rated effective resistance of 2400kN can be employed in thin seam coal faces. Basic requirements for coordination equipments of shearer are summed up while mining thin seams. According to successful experiences of extracting thin seams in similar geological conditions in China, the scheme of feasibility coordination equipments of shearer is optimized in thin seams with thickness of 0.8-1.4m and 1.1-1.9m, respectively. The conclusions will provide a reference value for Caoyao Coal Mine on carrying out mechanized mining of the mine, improving safety production capability, and prolonging the mine life.

Keywords: thin seam; shearer mining; equipment coordination; hard roof; soft coal

1. Mining status with shearer in thin seams

As to the selection of mining equipments, coal mining technology in medium-thick seams is similar to that in thin seams, the United States of America and other western countries call coal seams with the thickness less than 2.0m as the thin seams in line with practicability. Therefore, international definition is used to construct mines with safety and high efficiency, coal seams with thickness of 0.8-2.0m are also named as the thin ones. At present, both longwall mining home and abroad for thin seams has two technological methods: one is the fully mechanized mining equipped with shearer, scraper conveyer and hydraulic supports; the other is the fully mechanized mining using plow, scraper conveyer ( or running track) and hydraulic supports. Coal mining method with spiral drill has been widely applied in thin seams in Ukraine and China\textsuperscript{\textsuperscript{[1, 2]}}, and the latter represents Xinwen mining area.

Longwall mining by shearers and room-and-pillar mining with continuous miners have been implemented in thin seams in the United States of America and United Kingdom, while unmanned automatic mining has been carried out in thin seam coal faces with plows and hydraulic supports by electro-hydraulic control in Germany. From the conditions of their service, both shearers and plows have achieved better economic results, but each mining machine

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has a certain advantages and disadvantages to adapt to different geological conditions. Output in fully mechanized longwall coal faces in the United States of America has been in a leading position in the world, while annual output of 2.86Mt at coal faces of thin seam with thickness of 1.3-2.0m has been achieved, the efficiency of 411t per miners at coal faces has also been achieved. From 2004 to 2005, the United States of America had 52 longwall faces, in which 21 coal mines of thin seams with thickness were less than 2m (only one coal face with plow and 20 coal faces with shearsers). Annual output of coal face with plow was 15.9 million tons, while work efficiency of coal face was 1817 tons per miner. While annual output at coal face of shearer was 15.9-92.7 million tons, average annual output was 44.87 million tons, the average work efficiency was 3513 tons per miner. It showed that good economic and technical effects could be obtained with high-power winning equipments in thin seams with small thickness.

Presently, there are two kinds of shearsers in thin seams in China, i.e., ones which are imported and made in China. The latter of the series of MG shearer-loader are main models[5]. In 2006, on the geological conditions of thin seam whose dip angle is 3-6º, average thickness is 1.35m, and Protodyakonov coefficient is $f = 1.6$, Binhu Coal Mine in Zaozhuang City employed the following coordinating equipments: MG340-BWD1 shearer, ZY2400/0.9/2.0 hydraulic support and SGZ-730/320 scraper conveyor. With above coordinating equipments, the average yield of coal face was 80 thousand tons per month and the maximum yield was 3504 tons per day. Under the coal seam conditions of average thickness of 1.3m, both Daizhuang Coal Mine in Zibo City and Tongjialiang Coal Mine in Datong City achieved average yield of 6.8-8.0 million tons per month at coal face by Chinese shearer of MG series, the hydraulic supports with two-prop shielding and associated equipments.

Shearsers have a strong adaptability to geological conditions; it is suitable to excavate thin seams with hardness and thin seams with much diversification in thickness. One development trend on thin seam shearsers is to increase the total installed capacity with one or more motors of high power. So as to enlarge its application scope, increasing shearer power will be favorable to improve mechanical safety factor of equipment and its efficiency. Maximum general installed power rating on thin seam shearer in the world is more than 500kW. The other development trend on thin seam shearsers is changed in mode of traction from chain haulage of draw gear to chainless haulage or electric traction, so as to increase the adaptability of belt conveyor on coal seam floor, further improvement on the reliability of winning machines is needed.

2. Stability of surrounding rock of coal face and its control in thin seam in Caoyao coal mine

2.1. Brief introduction of coal face in thin seam

Caoyao Coal Mine belongs to one of four medium or small coal mines in the west of Yima mining area, the mine has excavated coal seam $B_1$ of Shanxi Formation at Permian System in Shanmian coalfield. Caoyao minefield situates in the east of the coalfield with the design capacity of 0.3 million tons per year. Rated capacity of the mine was 420 thousand tons per year in 2006. Annual output was 231.6 thousand tons in 2007 and residual mine life was 13.1 years. Then Caoyao Coal Mine has already come into post production in deep coal seam.

Coal seam $B_1$ is a minable one in the minefield, and the histogram of the seam is shown in Fig.1. Range of variation about thickness of the seam is wide, and the coal seam belongs to gently inclined, unstable and soft seam with thin-medium thickness. At present, the mine is excavating at blasting coal face 2503 with beams of $\pi$ type. Coal seam $B_1$ is an unstable and soft one whose Protodyakonov coefficient is $f = 0.16$. Thickness of the seam is 0.5-5.0 m, usually 0.8-2.0 m. Its dip angle is 13-18º, and average dip angle is 15º. Mining depth of the seam is about 330m. False roof over coal face is black shale or sandy shale with thickness of 0-1.5m. Immediate roof is off-white coarse-medium grained quartz and feldspar sandstone. The stratum of immediate roof is of cross-bedding and wavy bedding containing much muscovite. Its unilateral compressive strength is 46.6-212.4MPa. Floor of coal seam is black mudstone, charcoal mudstone and sand mudstone. The floor contains rich concretion with pyrite, small fossil fragments of plants. The lithology of floor is soft whose strength is lower, and uniaxial compression strength of rock is 18.43MPa. The bulk density of floor is 25.3kN/m$^3$. The histogram of coal seam is shown in Fig.1.
2.2. Classification on stability of surrounding rock of coal face in thin seam

(1) Classification of immediate roof

According to the characteristics of higher rock strength of immediate roof over coal face in thin seam, much development of joints and fissures in roof stratum, smaller stratification thickness, and the first caving interval for immediate roof $L_r$ (as a classification index for immediate roof) can be calculated.

First caving interval for immediate roof $L_r$ [6]:

$$L_r = 8.94 C_z \cdot \sqrt{R_{ci} \cdot h_{ci}}$$

$$= 8.94 \times 0.30 \times \sqrt{115.2 \times 0.3} = 15.8 \text{ (m)}$$

Where, $R_{ci}$ is uniaxial compressive strength of rock for immediate roof, 115.19MPa; $C_z$ is integrated weakening constant, 0.3; $h_{ci}$ is stratification thickness of immediate roof.

Based on first caving interval, immediate roof over coal face 2503 belongs to one with medium stability category of 2b.

(2) Classification of main roof

Basic roof over coal face 2503 is sandstone with higher strength and larger thickness. First weighting equivalent weight $P_e$ can be determined [7]:

$$P_e = 241.3 \ln(L_f) - 15.5N + 52.6h_m$$

$$= 241.3 \times \ln 22.0 - 15.5 \times 0.89 + 52.6 \times 1.4$$

$$= 805.7 \text{ (kN/m}^2)$$

Where, $P_e$ is first weighting equivalent weigh for basic roof, kN/m$^2$; $L_f$ is first weighting interval for basic roof, in which the value of actual measurement is 22.0m; $h_m$ is mining height, 0.8-2.0m; $N$ is immediate roof filling ratio of immediate roof thickness $h_i$ (0.9-1.6m) to mining height $h_m$: $N = h_i / h_m = 1.25 / 1.4 = 0.89$.

Based on the first weighting equivalent weight of basic roof $P_e$, basic roof over coal face 2503 belongs to one of
non-obvious weighting with level one in accordance with classification standards for basic roof.

(3) Classification of floor

The floor of coal face 2503 is the carbonaceous shale and shale with less thickness of stratum, lower compressive strength and easy softening while meeting with water. Based on average uniaxial compressive strength of 18.4MPa for shale floor, its permitted uniaxial compressive strength of 13.8MPa can be figured out. The floor belongs to much soft floor of category 3a in accordance with classification of the floor of coal face.

2.3. Control degree of surrounding rocks and types of supports

Based on combination of immediate roof with category 2b, basic roof with level one and floor with category 3a at coal face 2503, surrounding rocks of coal face belong to the easy control of G, i.e. control on surrounding rocks of basic roof and floor is easy. Consequently, in order to reduce labor intensity of miners and improve safety production capability of coal face, under the geological conditions of thin seam B1 in Caoyao Coal Mine, mechanized mining can be implemented by the hydraulic supports of supporting-shielding type or light-shielding type.

2.4. Rated Effective Resistance of Hydraulic Supports

According to type of surrounding rock of coal seam B1, lower limit of rated supporting intensity at coal face $P_S$ can be figured out

$$P_S = 72.3h_m + 4.5L_P + 78.9B_c - 10.24N - 62.1$$

$$= 72.3 \times 2.0 + 4.5 \times 9.0 + 78.9 \times 2.5 - 10.24 \times 0.89 - 62.1$$

$$= 311.1 (kN/m^2)$$

(3)

Where, $P_S$ is lower limit of rated supporting intensity at coal face, kN/m$^2$; $h_m$ is mining height at coal face, 0.9-2.0m; $L_P$ is interval of periodical weighting of basic roof, $L_P = L_f / 2.45 = 22.0 / 2.45 = 9.0$ (m); $B_c$ is width of face roof under control of supports (the value is the distance from beam end to faceline), 2.5m; Other parameters are as the former.

In accordance with height of strata over support at coal face, supporting intensity on support can be determined with the approximation method. Then the rated supporting intensity of support at coal face is:

$$P_M = 8h_m \cdot \gamma$$

$$= 8 \times 2.0 \times 25 = 400.0 (kN/m^2)$$

(4)

Where, $\gamma$ is average bulk density of overlying strata on support at coal face, 25kN/m$^3$; other parameters are as the former.

While comprehensive mechanized mining is implemented in coal seam B1 in Caoyao Coal Mine with shielding hydraulic supports, rated effective resistance $F_s$ on light hydraulic support can be calculated in line with rated supporting intensity $P_M$ on hydraulic support at coal face. The calculated value is the basis for selecting hydraulic supports; the actual selection of rated effective resistance on hydraulic support should be equal to or more than the data below.

$$F_s = P_M \cdot (S_c \cdot B_c / K_s) \cdot C_k$$

$$= 400.0 \times (1.50 \times 2.5 / 0.8) \times 1.25$$

$$= 2343.75(kN) = 2400kN$$

(5)

Where, $F_s$ is rated effective resistance on hydraulic support, kN; $P_M$ is rated supporting intensity on hydraulic
support, 400.0kN/m²; \(S_c\) is width of hydraulic support, 1.50m; \(K_s\) is supporting efficiency of hydraulic support, 0.80; \(C_k\) is reserve factor of effective resistance for hydraulic support, 1.25.

Based on the criterion for types and parameters of hydraulic supports in longwall faces in China, two-prop shielding hydraulic support with 2400kN can be employed in thin seam coal faces in Caoyao Coal Mine, which rated effective resistance on one prop of hydraulic support is 1200kN.

3. Coordinating equipment in mining thin seam in Caoyao coal mine

The problem of coordinative composition of equipments at coal face is the precondition for studying mechanized mining with shearer in thin seam. Under the geological conditions of hard roof and soft seam in Caoyao Coal Mine, coordinative composition of equipments at coal face need to solve the following problems: (1) type selection of coal winning machines; (2) choice of supporting equipment; (3) selection and design on transporting equipment; (4) question of coordinative composition of equipments at coal face, including equipments above matching their production capacities, performances and cross sectional sizes etc.

3.1. Requirements on coordinating equipments in mining thin seam

Equipments of coal face in thin seam include shearer, hydraulic supports and scraper conveyor, i.e., “three machines”. Reasonable equipments coordination needs to achieve the best combination among equipments in order to make the optimal economic and technical effects of coal face. Then, requirement of coal face in thin seam is matched with the cross sectional sizes of equipments, production capacities and performances on “three machines”, so that maximum safety production capacity can be achieved at coal face.

(1) Requirements on hydraulic supports

After the type of hydraulic supports of coal face in thin seam is selected, the following basic elements should be taken into account:

1. Type of hydraulic supports and their ratio of extension to retraction. The two-prop and shielding hydraulic supports with integer roof beams usually are employed at coal face in thin seams. The supports are bigger ratio of extension to retraction in order to adapt to larger diversification in mining height of coal face in thin and thinner coal seam.

2. Hydraulic supports should have higher effective resistances to avoid being pressed to death.

3. Hydraulic supports have higher strength and reliability.

4. Hydraulic supports have higher degree of automation and meet the requirements on supports rapidly moved.

The main parameters of hydraulic supports in thin seams are limited in design specifications for hydraulic supports in China. Moving hydraulic support can be done while the support is unloaded at coal face. In order to avoid hydraulic supports from being pressed to death, requirements on supports are that, maximum height of supports must be equal to the maximum mining height of coal face adding 100-200mm; and minimum height of supports equals to or less than the minimum mining height of coal face subtracting 150-250mm. Center distance of adjacent supports is 1.5m. The distance from beam-end to faceline is 200-350mm.

The speed of moving support must be adapted to the traveling speed of cutting coal with shearer. Usually, support moving speed at coal face should be larger than the speed of cutting coal with shearer.

(2) Requirements on shearsers

Since mining height of coal face in thin seam is lower, it requires shorter body of shearer with sufficient power. The length of complete shearer should be as short as possible, in order to be adapted to vary in fluctuation of floor. Thin seam sheares can be divided into two types: riding conveyor shearsers and climbing floor ones. The former excavate coal seams with the thickness of more than 0.8-0.9m; the latter excavate coal seams with 0.6-0.8m thickness. At present, electrical traction shearsers made in China such as MG200/450/W and MG300-BW1 type, are new types of high-power shearsers in thin seams, where average mining height of coal face is about 1.2-1.3m.

(3) Requirements on scraper conveyor

Requirement while mining thin seam is to reduce the height of the central trough of scraper conveyor. Since the height of shearer in thin seam becomes thinner, and width of shearer increases, so increasing conveyor width is needed in order to ensure longitudinal center of conveyor gravity to coincide with that of shearer. Thus, while
cutting coal or rock with shearer, the vibrations which make work instable for the coordination equipments can be avoided. The principles of main parameters of scraper conveyor are as follows: ① its transport capacity should be consistent with cutting capacity of shearer; ② its motor power is determined by transport capacity and length of scraper conveyor.

3.2. Scheme of coordinating equipment in mining thin seam in Caoyao coal mine

(1) Scheme of coordinating equipments at coal face with mining height 1.1-1.9m

According to successful experience of mechanization mining in thin seam in China, the type of surrounding rocks of coal face and rated effective resistance of support in Caoyao Coal Mine, two-prop and shielding hydraulic supports of ZY2400-0.8/1.9 can be employed at coal face in thin seam in line with design specifications for hydraulic supports in China. Main technical parameters of the supports are that their effective resistance and supporting intensity are 2400kN and 0.46MPa, respectively. Coordination equipments at coal face in thin seam contain MG200-BWl shearer (drum diameter is 1 100mm and travel speed is 0-6.13m/min) SGZ-630/220 scraper conveyer (transport capacity is 450t/h), and MRB-125/31.5 emulsion pump. Coordination equipments of shearer are shown in Table 1.

Table 1. Scheme of coordination equipments at coal face with mining height 1.1-1.9m in Caoyao Coal Mine

<table>
<thead>
<tr>
<th>Name of equipments</th>
<th>Type of equipments</th>
<th>Number of equipments</th>
<th>Main technical parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shearer</td>
<td>MG200-BWl</td>
<td>1</td>
<td>Power 200kW; Mining height 1.1-2.0m</td>
</tr>
<tr>
<td>Hydraulic support</td>
<td>ZY2400/10/19</td>
<td></td>
<td>Effective resistance 2400kN; Supporting height 1.0-1.9m</td>
</tr>
<tr>
<td>Scraper conveyor</td>
<td>SGZ-630/220</td>
<td>1</td>
<td>Motor Power 2X 110kN; Transport capacity 450t/h</td>
</tr>
<tr>
<td>Bridge conveyer</td>
<td>SZB-730/40</td>
<td>1</td>
<td>Motor power 40kW; Transport capacity 630t/h</td>
</tr>
<tr>
<td>Emulsion pump</td>
<td>MRB-125/31.5</td>
<td>2</td>
<td>Rated flow 125L/min; Rated pressure 31.5MPa</td>
</tr>
</tbody>
</table>

The above-mentioned of equipments of shearer are tested and have been applied in thin seam with gently inclined instability in Tianchen Coal Mine of Zaozhuang mining area whose geological condition is similar to that in Caoyao Coal Mine. The thickness of the seam in Tianchen Coal Mine is 0.8-2.3m, average thickness is 1.65m and dip angle is 8-13°. The false roof of the seam is sandy mudstone with thickness of 0.2-1.8m, its immediate roof is 3.8m thick sandy shale, and main roof of the seam is 28m thick sandstone. The immediately floor consists of carbonaceous shale and mudstone with thickness of 2-4m. The average yield of 50 thousand tons per month and maximum yield of 85 thousand tons per month is obtained at coal face with this set of equipments. Therefore, the set of equipments can be directly employed to excavate coal seam B1 with thickness of 1.1-1.9m in Caoyao Coal Mine.

(2) Scheme of coordinating equipments at coal face with mining height 0.8-1.4m

Table 2. Scheme of coordinating equipments at coal face with mining height 0.8-1.4m in Caoyao Coal Mine

<table>
<thead>
<tr>
<th>Name of equipments</th>
<th>Type of equipments</th>
<th>Number of equipments</th>
<th>Main technical parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shearer</td>
<td>MG300-BW</td>
<td>1</td>
<td>Power 300kW</td>
</tr>
<tr>
<td>Hydraulic support</td>
<td>ZZ2200-0.7/1.35</td>
<td></td>
<td>Effective resistance 2200kN; Supporting height 0.7-1.35m</td>
</tr>
<tr>
<td>Scraper conveyor</td>
<td>SGZ630/150</td>
<td>1</td>
<td>Motor Power 2X 75kN; Transport capacity 450t/h</td>
</tr>
<tr>
<td>Bridge conveyer</td>
<td>XRB2B-80/350</td>
<td>2</td>
<td>Rated flow 80 L/min; Rated pressure 30MPa</td>
</tr>
<tr>
<td>Scraper conveyor in headgate</td>
<td>SGW-80T</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Based on successful experience of mining thin seam in Datong No.1 Coal Mine of Songzao city, Coordination equipments of shearer in thin seam with thickness of less than 1.4m in Caoyao Coal Mine are shown in Table 2. The set of equipments of shearer consists of MG300-BW shearer, supporting-shielding hydraulic supports with ZZ2200-0.7/1.35 type, SGZ630/150 scraper conveyor and XRB2B-80/350 emulsion pump. These coordinating equipments have been successfully applied to six gassy mines of Songzao C&E Co.Ltd., of which Datong No.1 Coal Mine excavates thin seam with thickness of 0.6-1.4m. In 2007, the average yield of coal face in Datong No.1 Coal Mine was up to 34 thousand tons per month, and average work efficiency was 16.68 tons per miner; while the maximum yield was up to 45 thousand tons per month, so safety and high-efficient mining was realized in thin seam.

4. Conclusions

Study status on mining thin seams with shearer in the world is summed up. Basing on the geological conditions of hard roof and soft thin-seam with instability in Caoyao Coal Mine, stability classification on surrounding rocks of coal faces is studied. It concludes that the type of strata control on thin-seam coal face belongs to “comparatively easy”. So, light hydraulic supports can be used in thin-seam coal face. Basic requirements for coordinating equipments of shearer while mining thin seam are summarized. Two sets of coordinating equipments of shearer in Caoyao Coal Mine are put forward in line with successful experiences of mining thin seams in China.

According to the criteria for classification on strata stability of gently-inclined coal faces in China, and combined with surrounding rocks conditions of coal faces in Caoyao Coal Mine and related parameters of strata behaviors of coal faces, the paper concludes that strata control on thin-seam coal face is comparatively easy, and degree of control on surrounding rocks belongs to the easy type. Two-prop and shielding hydraulic supports whose rated effective resistance are equal to or more than 2400kN, can be employed at thin seam coal faces in Caoyao Coal Mine.

Basic requirements for coordination equipments of shearer mining at thin seam are studied. Based on the geological conditions of thin seam in Caoyao Coal Mine, the scheme of feasible coordination equipments of shearer is optimized in 0.8-1.4m and 1.1-1.9m thick seams, respectively. The scheme includes the type and main parameters of shearer, hydraulic supports and scraper conveyor etc.

The development direction of coal industry in China is to improve the level of mechanization of coal mines and increase their production capacity with safety and high efficiency. The conclusions will provide a reference value for Caoyao Coal Mine to carry out mechanized mining in thin seam, improve its safety production capability, and prolong the mine life.

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