HONGZE ZHAO
YU LIU
and
QUNFEI ZHENG

Research on a new application mode of semi-continuous comprehensive mining technology for large opencast coal mines

Since the reform and opening up, with the development of continuous mining technology and scale expansion of open pits, the design philosophy of current mining procedure and mining technology has gradually lagged behind. For the development of large-scale opencast coal clusters in china, the paper analyzed the backward design philosophy of traditional industrial square-centered mining procedure under the original shovel-truck technology, and put forward a new design idea of banded subarea mining. On this basis, for large-scale open pits, the paper further proposed the stripping technology of shovel – self advancing crusher – double-face belt conveyor in combination with the raw coal transport technology of shovel – truck – simple mobile crushing station – end slope belt conveyor. These new technologies have already been applied to Pingshuo East surface mines, providing references for future development of China's large-scale opencast coal mines.

Keywords: *Opencast coal mines, Mining procedure, Semi-continuous mining technology, Self-advancing Crusher, Coal cluster.*

1. Introduction

As more coals are needed for the economic growth in China, the present discovery and development of large-scale domestic opencast coal mines mount up. The design and development of large-scale open pits in areas of Pingshuo, Zhunge'er, Baiyinhua, Shengli, Zhundong and Sha Ehu have brought a new development stage for opencast working in China. New problems arise along with the increase of mining theories and practices. Specifically, although the exploitation of coal clusters is always required for multiple large-scale open pits in a certain coal mining area, traditional theories and patterns of single exploitation remain instructional in current technological design and advancement of coal clusters. As a consequence, mine resources are wasted, and the overall development profits are reduced as well. Despite of a few relevant domestic studies [1-6], there is still rare public research achievements in aspects of mining area division and technological application in the coal cluster mode.

Technological development determines the change of mining procedures. The railway technology had been used since the founding of PRC, and it was replaced with the shove – truck technology after the reform and opening up. Nowadays, the semi-continuous belt technology has been put into extensive use. For the mode of mining area division, the long all-area mining mode with the shovel – railway technology was once used, following the short subarea mining mode with the shovel – truck technology. Currently, it has upgraded to the long subarea mining mode with the semi-continuous belt technology, which, with more flexibility, fits better into the wide range of large-scale opencast coal mining.

2. Analysis of long subarea mining area division

2.1 Advantages and disadvantages

The traditional method of external dumping-based mining area division takes the core factor into account that efficiency and cost of discontinuous transportation are affected by haul distance. For the generally extensive areas of large-scale open pits, the working line will be too long if single exploitation is done in the areas. Meanwhile, considering factors of preliminary capital construction capacity, exploration degrees, stripping ratios, production scales, economic benefits, and specification of equipment, subarea mining near an industrial square is always used for large-scale opencast coal mining, where reasonable lengths of working lines help determine the width of different subareas (Fig.1).

As the exploitation mode changes to internal dumping-based belt transportation, and considering the shortage of traditional mining area division, it is popular in practice to transport coals by means of traceable internal waste dumping at close ranges and belt conveyors. In this connection, it is supposed to use the mode of long mining area division for large-scale opencast coal mining, whose main characteristics are as follows.

(1) Long mining area division can help maintain prolonged continuous advancement and reduce steering times as well,

Messrs Hongze Zhao, Yu Liu and Qunfei Zheng, State Key Laboratory of Coal Resources and Safe Mining, Faculty of Resources and Safety Engineering, China University of Mining & Technology (Beijing), Beijing 100083, China, Email: Hzzhao78@163.com

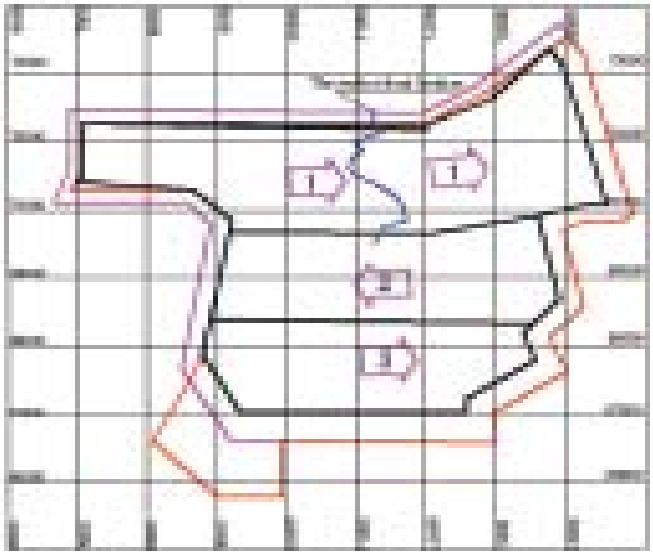

Fig.1 The traditional method of mining area division

thus escaping from a series of short-division problems such as end slope pressure, enlarged steering transport distance, insufficient soil dumping space, and complicated production organization and management. Since both the state government and local governments have tightened up land management by issuing a series of policies on land expropriation in China, opencast coal mines are witnessing a constantly increasing land use cost and even more difficult land expropriation. The overall mining procedure for open pits may even change due to sluggish land expropriation or corresponding disputes. Therefore, the long mining area division has its advantages stand out.

(2) Free from steering constraints, the long mining area division can realize end slope expansion flexibly in accordance with production requirements. The length of working lines can change to a great extent. Meanwhile, with possible prolonged mining in certain areas for mining equipment, the equipment mobilization during the process of steering can be lessened, and the working lines become less uneven, hence ensuring fully efficient usage of mining equipment.

(3) As the stope develops continuously, the exploration and transport system will stretch to the next mining spot with low workload, good continuity, simple systems, stable material flow, little equipment mobilization, and small interference of material haulage. What's more, to use the fixed mode for a long period is to enhance mining efficiency significantly. Corresponding organization and management will become convenient and efficient.

(4) As long mining lengths are needed for long mining areas, during coal mining area division, it is supposed to maintain as long lengths as possible for each coal mining area that is ought to be rectangular. The type of soil dumping for such mining areas shall be either internal dumping-centered or internal dumping. Transport systems are not limited by transport distances. Mining area width shall guarantee that the working lines be optimized. The mining area borders shall be partitioned as naturally as possible. Steering shall be reduced.

2.2 Parameter design

(1) Transport distance for internal waste dumping

For the dumping sites in long mining areas, traceable internal waste dumping is adopted after the capital construction is completed. Wastes in mining areas are transported to internal dumping sites through end slope haulage, thus the transport distance is limited to a fixed range. The general equation for the transport distance is:

$$D_{Tj} = \frac{\nabla H_j}{i} C_q + \frac{L_j + L_j'}{K} + \frac{H_j}{\tan\beta} + \frac{H_j}{\tan\varphi} + S \quad (1)$$

where, D_{Tj} - the transport distance between the jth bench and the internal dumping site, m; ∇H_j - the altitude difference between the barycentre of the jth bench and that of the dumping bench, m; i - limiting gradient of road, generally between 8%-10%; C_q - the coefficient of road line extension; L_j- the length of the working line for the jth bench, m; L_j' - the length of the working line for the dumping bench that corresponds to the jth bench, m; K - the coefficient, with the value of 4 for double rings and the value of 2 for a single ring; H_j - the altitude distance between the barycentre of the jth bench and the pit's bottom, m; β - the angle of the working slope, °; φ - the slope angle of the dumping site, °; S - the safety distance between the bottom bench of the mining area and that of the dumping site, m.

The equation of L_j is:

$$L_j = L_D + 2H_{jctg}\beta \quad ... (2)$$

where, α - the angle of the end slope, °; L_D - the length of the working line in the pit's bottom, m.

Thus, the equation of comprehensive transport distance for pit wastes is:

$$D_T = \frac{\sum_{j=1}^{n} D_{Tj} = T_j}{\sum_{j=1}^{n} T_j} \quad ... (3)$$

where, T_j - the volume of the ith bench, m³.

(2) Capacity of the dumping sites

For long area mining, it is generally possible to discharge dumping wastes into internal dumping sites. Although its volume increases as the waste become loose, the excavation of raw coals can make room for part of the waste. Thus, the remainder of internal dumping space is calculated as:

$$V_\circ = P_s n_s (\eta - 1) - \frac{P_s}{\gamma} \quad ... (4)$$

where, V_o - the remainder of internal dumping space, m³; η - the loose coefficient of the waste; P_s - raw coal production, t; n_s - the stripping ratio for production, m³/t; γ - the volume weight of the coal seam, t/m³.

As can be seen from equation (4), the stripping ratio decides directly whether the internal dumping space is enough or not. If not, height increase or external dumping is needed. According to the occurrence characteristics for open pits in China, the stripping ratio is generally below 6. Therefore, most of the open pits are able to realize full internal dumping (except for the open pits with large dip angles).

3. Analysis of typical application of the semi-continuous technology for opencast coal mines under the mode of long area mining

With great flexibility, the shovel-truck technology is suitable for use in exploitation and transportation under complex geological conditions. What's more, on the premise that coal production has met the requirements, traceable full internal dumping can be realized where the transport distance will be maintained within the reasonable range of 3km all along. The rock stripping system of major large-scale open pits, which either are newly built or have reached output, is mostly designed to be equipped with the shove-truck discontinuous technology or the "shovel-self advancing crushing station-belt conveyor" semi-continuous technology. For the coal mining system, considering that there is inclining change along strike for coal seams, that the coal seams are far from coal storage sites, and that coal crushing is needed before coal washing, the "shovel-truck-mobile/semi stationary crushing station-belt conveyor" semi-continuous technology is preferred in most cases.

In light of coal mine scales, most of the open pits in China can be divided into two types: large-scale open pits with big advancement and small-scale open pits with small advancement.

(1) Large-scale open pits with big advancement

This type is characterized by great annual stripping amounts, numerous stripping benches, and high mining strength. Typical cases include the Pingshuo open pit and the Zhunge'er open pit.

(2) Small-scale open pits with small advancement

This type is characterized by small annual stripping amounts and less stripping benches. Typical cases include the Shengli open pit, the Yimin open pit, and the Baiyinhua open pit.

For large-scale open pits with big advancement, the annual workload for a single bench at upper coal seams can reach above 10Mm^3, because of high mining strength, fast advancement, farther comprehensive transport distance for upper overburden with medium-high hardness than the reasonable transport distance by truck, great annual stripping amounts, and numerous stripping benches as well. In this connection, it is necessary to use high-capacity systems with semi-continuous technology, for which shovels with the capacity of 55m^3 or above shall be equipped. Thus, 300-ton trucks or even over-360-ton trucks shall be provided for both the system with the shove-truck discontinuous technology and the system with the "shovel-self advancing crushing station-belt conveyor" semi-continuous technology. This will lead to big investment and high operating cost due to continuous shifts. To control cost, recent years have witnessed successful research and manufacture of 8000-10000t/h self-advancing crushing stations, which have been applied to open pits and oil sand pits successfully. The semi-continuous system of self-advancing crushing stations has an obvious cost advantage because it can better solve problems of additional expenses for fuel oils, tires, and maintenance of the trucks. Therefore, this system usually takes priority for overburden stripping in upper benches if the occurrence is suitable.

If the semi-continuous technology is adopted for upper overburden stripping, impenetrable belt conveyors will be placed in the stripping area, the dumping sites, and the end slopes as well, which will complicate the layout of the whole coal mine exploitation and transport system. It is hence supposed to avoid mutual interference between coal mining and coal stripping in the overall mining system layout scheme. In addition, as the open pit outputs mount up, both the length and advancement degrees of the working lines increase, leading to a prolonged transport distance for raw coals. Thus, the mobile crushing station with roadway coal haulage is used for raw coal transportation, aiming to help reduce the interference between coal mining and coal stripping, shorten the transport distance, cut down transport cost, and make the realization of coal blending easier.

3.1 The semi-continuous system with stripping self-advancing crusher and double-face belt conveyor

The main production link and equipment in the semi-continuous technology system with self-advancing crusher and double-face belt conveyor are shown in Fig.2. As can be seen, the production link contains such equipment as shovel excavator, self-advancing crusher, two sets of mobile belt conveyors for mining faces, end slope semi-stationary belt conveyor, stationary hoist belt conveyor, mobile belt conveyor for dumping faces, and dumping plough.

The blasted loose materials are shoveled and sent to the feed hopper of the self-advancing crusher, and then enter the double roll crusher through the heavy-duty slat feeder, in which the materials are crushed until the granularity satisfies the demand. Then, the crushed materials are released in the dumping system directly through the relief hopper. Composed of relief arms of the self-advancing crusher and independent belt bridges, the dumping system is used to transport the crushed materials to the face belt conveyor. The operating

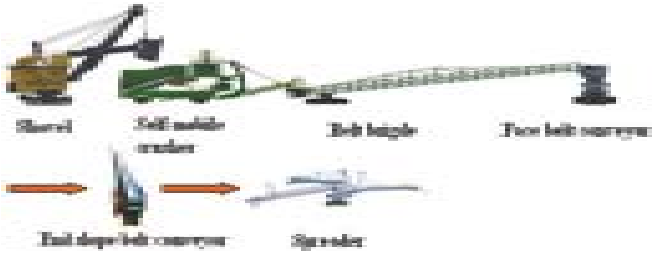

Fig.2 The main link in semi-continuous technology system with self-advancing crushers& double face belt conveyor

Fig.3 The material conveying flow in semi-continuous technology system

room lies on top of the crushing station, with a bird-eye view of the whole material transport path, the process of crushing and feeding in particular. The specific material conveying flow is shown in Fig.3.

For the new double-face belt conveyor system, the traditional stage loader is replaced with the addition of a working face belt conveyor. The advantages of it are: (1) the shifting of working face belt conveyors will not interfere with system operation; (2) the new system is more suitable to height change of grouped benches due to topographic relief or change of the main production capacity; (3) efforts are spared in shifting materials across benches, thus reducing the difficulty in aligning the feed point and the dumping point.

3.2 The semi-continuous system with coal mining end slope roadway and mobile crushing station

The coal mining mobile crushing station technology system is composed mainly of shovel excavator, truck, simple mobile crushing station, and end slope belt conveyor (Fig.4).

The horizontal layout is adopted for simple crushing stations in the working faces, and the horizontal small-angle hoist layout is adopted for the scraper conveyor. For the simple crushing station that is located at the end slope generally, dump trucks are used for the process of loading and transport. The materials will be unloaded in the flexible scraper conveyor at the end slope. After being crushed in the crusher on top of the belt conveyor, the materials are

Fig.4 The main links of simple crushing station system

transported to the conveyor, while the rest bulk materials are sent to the scraper conveyer by dumping plunge or by front loader.

The simple mobile crushing station has combined the advantages of semi-stationary crushing stations and those of mobile crushing stations. The traditional steel-made storage bins and supporting structures are spared. Both the open horizontal sides of the round-link chain scraper feeder are free from raising baffles. The dump trucks can discharge materials directly to the feeder. The height of both the naturally formed storage bins and the dump trucks can be controlled manually by bulldozer. In addition, modular design is adopted to the simple mobile crushing station, with compact structure and light weight. As an integrated module, the crusher's platform makes it convenient for flat trucks to transport materials. Shifting of the round-link chain scraper feeder can be done either horizontally or slantwise, as there are supportive slides in the climbing area. Electric cabinets are easy to move as a whole. What's more, the time-saving plug-in structure that is easy to dissemble is used for control and external signal lines. All in all, the whole shifting process costs 3 to 5 days.

The end slope lanes mainly mean that a big transportation lane is designed at the end slope in open pits, on which the belt conveyor transports crushed coals to the storage bins (Fig.5). The forms of the big transportation lane contain horizontal lane, slant lane, ore pass and the combination of them.

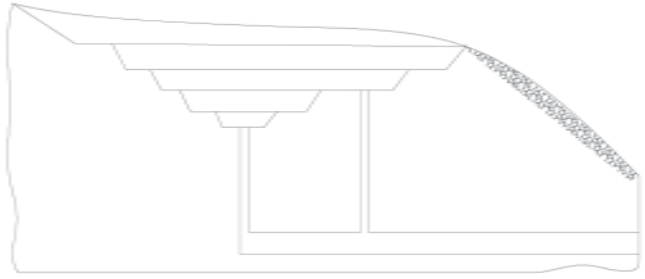

Fig.5 Typical layout of transportation lane at the end slope in open pits

4. Case study of the pingshuo east open pit

The overlying coal strata within the mining boundaries of the Pingshuo East open pit was simple, with the dip angle of between 2° and 7° (generally under 5°). There were altogether 7 minable coal seams, where No. 4, No. 9, and No. 11 were the main minable seams, and No.5, No. 6, No.7, and No.8 were the partially minable coal seams. Its scale was designed to be 20Mt/a, its annual stripping amount 110Mm^3/a, and its mining depth between 160m and 270m.

4.1 Mining parameters for stripping design

The mining parameters for the semi-continuous system with stripping self-advancing crusher and double-face belt conveyor were: the bench width for a single blast was 40m, the maximum stretch distance of the blasted piles was 20m,

and the required safety distance between the bench toe of the blasted rock and the belt conveyor on the same bench was 50m. The double-bench mining form was adopted. According to the requirements of equipment layout for the technology system and the parameter specifications that satisfy the working berm, the single excavation width was determined to be 30m. Fig.6 shows the working berm elements.

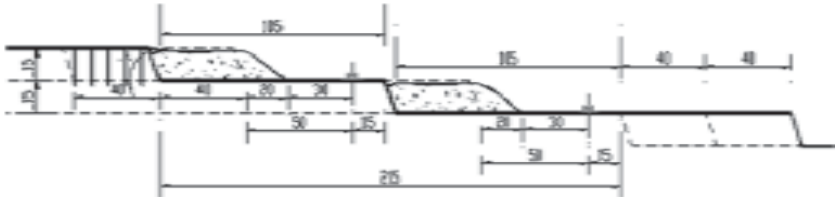

Fig.6 Working berm elements

4.2 System design for the raw coal system

Hydraulic excavators were used for the mining face in the Pingshuo East open pit. 200-ton dump trucks transported the excavated materials to the self-advancing crushing station at the end slope, where the materials were crushed under the granularity of 300mm and then sent to the belt conveyor system before heading to the coal preparation plant. Two sets of self-advancing crushing station with the production capacity of 3,000t/h were designed for coal treatment separately at the south end slope of the No.4 coal seam and that of the No.9 coal seam, transporting the crushed coals through the belt conveyor system to the ground for a second crush. They, the treated coals were sent to the original storage bin for storage, waiting for coal washing and external transportation.

Fig.7 shows the three-lane layout of the underground coal transport system in the Pingshuo East open pit, namely the No. 4 coal transport lane, the No.9 coal transport lane, and the auxiliary transport lane to the south of the No.4 coal transport lane. The third lane was also used for air inlet. All of the three lanes lied in the industrial field. After being crushed in the self-advancing crushing station at the end slope, the raw coal was transmitted to the No.4 end slope belt conveyor and the No.9 end slope belt conveyor, respectively. Then, it was transmitted to the No.4 coal transport lane and the No.9 coal transport lane.

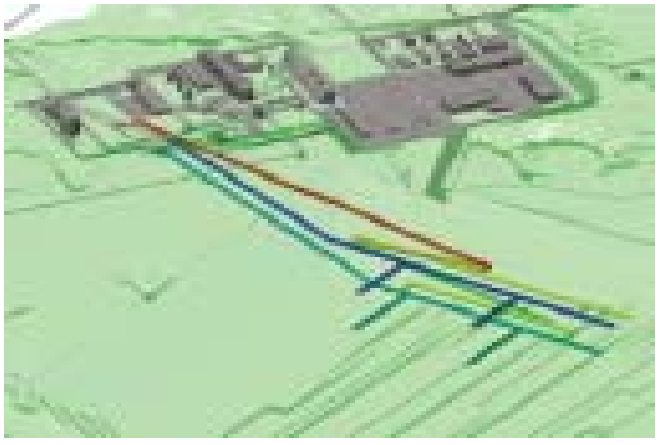

Fig.7 The schematic diagram of the coal transport system in the Pingshuo East open pit

5. Conclusions

(1) As the production scales and mining technologies of open pits continue to develop, it has become a future trend to use the semi-continuous mining technology for large-scale opencast coal mines. With the advantages of less steering times and the ability to increase production efficiency and outputs, the long subarea mining is inevitable to become the development tendency of mining procedures to match up the reform of mining technologies.

(2) Due to great annual stripping capacity, numerous stripping benches, and high mining strength, the large-scale open pits with big advancement shall give priority to the "shovel-self advancing crushing station" stripping technology. Meanwhile, to reduce the mutual interference between soil dumping and coal transport, the mobile crushing station and end slope lane shall be preferred for raw coal transport.

(3) The simple mobile crushing station is characterized by easy and flexible realization of feeding, layout, and shifting, low initial investment, high adaptability to changeable industrial and mining conditions, and low operating expenses. The new technology system of shovel-truck-simple crushing station-end slope lane belt-ground belt-storage bin has become the first choice for mining technologies under complex geological conditions.

(4) The self-advancing crusher moves with electric shovels instead of trucks on the working faces. In this connection, due to the cost saving, energy conservation and emission reduction, it is called as "green mining". Compared to the traditional self advancing crushing station-(stage loader)-single face belt conveyor technology, the self advancing crusher-double face belt conveyor technology has more advantages in adaptability to complex geological conditions and system efficiency. Specifically, the shifting of working face belt conveyors will not interfere with system operation; the grouped bench is more suitable to height change; and the difficulty is reduced in aligning the feed point and the dumping point of the stage loader.

6. Acknowledgment

The work was supported by State Key Laboratory of Coal Resources and Safe Mining (No. SKLCRSM14KFB12) and supported by the fundamental research funds for the Central

Universities (No. 2013QZ04)".

References

[1] Bai R. C., Liu C., Xue Y. D., Liu G. W., Cao B. (2014): Coordination mining technology for coal underlying the slopes between two adjacent open pits. *Journal of China Coal Society*, 39(10): 2001-2006.

[2] Cai Q. X. (2011): Domestic hundred million tons class of open-pit coal mine groups and open-pit coal green mining technology. *The seventh Conference of coal science and Technology proceedings*, 243-252.

[3] Cao C. J. (2012): Discussion on Mining Technology of Surface Mine Group in Erdos Area. *Coal Engineering*, (12): 16-18.

[4] Liu X. Q., Duan Q. C.. (2006): Optimization of Mining Sequence in surface mines of An Tai Bao. *Coal Engineering*, (11): 5-6.

[5] Zhang R. X., Wang Z. Q., Yu R. S. (1998): Optimization of Mining Sequence for Open Pits. *China Mining Magazine*, 7(1): 48-52.

[6] Zhang R. X., Gao Y. S., Li H. H., Mei X. R. (2003): Optimization method of open-pit mining sequence and its applications. *Journal of China Coal Society*, 28(5): 491-495.

[7] Shang T., Cai Q. X., Chen S. Z., Zhou W., Zhang G. Y. (2010): Working Face Parameter Optimization for a Semi-continuous Technology Having a Self-advancing Crusher. *Journal of China University of Mining & Technology*, 39(6): 820-825.

[8] Che Z. X., Cai Q. X., Ji C. S., Li K. M. (2000): Study on Half Continuous Technology of Topsoil Stripping in Surface Mines. *Journal of China University of Mining & Technology*, 29(1): 110-112.

[9] Zhang Y. Y. (2011): The application and development strategies of semi-continuous mining system in Chinese surface coal mines. *Journal of China Coal Society*, 36(5): 756-761.

[10] Zhang G. Y., Cai Q. X., Zhou W., et al. (2010): Reliability study on semi-continued system of self-moving rusher in yiminhe surface mine. *Coal Engineering*, (7): 42-44.

[11] Z. L. Dong, B. W. Wang. (2010). Research on semi-continuous mining system. *Mining & Processing Equipment*, 38(15): 39-41.

[12] China University of Mining and Technology, *Open-pit Ming Engineering Manual (the fifth volumes)*, Beijing: China Coal Industry Publishing House, 1986.

[13] Yang R. X. (1986): *Open-pit Ming Engineering*. Xuzhou: China University of Mining and Technology Press, 2.