Application and Development of Smart Mine in China

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Abstract. The development of coal mining from ancient times to today has experienced the artificial stage, the mechanized mining stage, and the automated mining stage. Now it is developing towards a safer, greener and more efficient unmanned and smart mine. This article suggests that the development of smart mine is a process of continuous improvement. The overall goal of the smart mine is divided into three development stages, from the smart working face and driving face (1.0 era) to the smart of the whole mine (2.0 era), and finally to the subversion of smart mining technology (3.0 era), the state and coal enterprises have given great attention. At present, there are more than 40 mining areas to carry out smart mine construction plans, but there are still many unresolved problems; Finally, it gives a prospect for the development and realization of Smart Mine.
Keywords: Smart Mine; Unmanned mining; Development path

1 Introduction

The rapid development of science and technology, a new generation of research such as big data, high performance computing, artificial smart calculation and other information technology is becoming more widely, promoting geological information science major step forward towards a more smart goal , Smart Planet[1] concept came into being. Smart Mine is a part of the construction of Smart Planet. Smart Mine[2] is an unmanned mine that actively senses, automatically analyzes, and quickly processes towards the production, occupational health and safety, and technology. The essence of Smart Mine is safe mines, high-efficiency mines, and clean mines; Mines including coal mine, metal mine and non-metal mine. This paper takes coal mine as an example to illustrate.

Coal mining has experienced four stages from ancient times to present era.It is artificial mine stage, mechanized mine stage, automated mine stage and Smart Mine stage. In the artificial stage, people mainly carry out mining activities by manual and simple tool drafting and digging, and the production mainly depends on manpower, and the efficiency is extremely low; In the mechanical mine stage, the manual operation is replaced by mechanized production. The mines use a large amount of mechanical equipment and

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blasting construction in mining, transportation, upgrading and production assistance. The number of mine workers is greatly reduced. The safety production technology support capability and the level of safety production of coal mine enterprises is greatly improved; In the stage of automated mining, coal mine enterprises comprehensively digitize comprehensive information such as mine geography, geology, mine construction, mine production, mine safety, coal mine transportation et al., so as to realize the improvement and integration of integrated automation systems, and carry out the initial construction of management informationization and engineering digitization, to achieve automated mines; Smart Mine is based on the research of mechanical mine and automated mine, awareness-based mining research on coal mining enterprises through integrated automation, information management and engineering digital of mastery, combined with Internet + [3], artificial smart, big data [4], virtual simulation, visualization, spatial information technology, network integration and cloud technology, 3D simulation and virtual reality and other advanced information technologies in an efficient, safe, green mining as the goal, the construction of highly smart, automated, user-friendly smart of mine, to create a " unmanned mining "mode of production as the ultimate goal, to realize Smart Mine [5-7]. Over the past decade, coal mining technology and equipment developed rapidly, significantly increasing mechanization and automation, providing a solid foundation for the smart exploitation. But now the majority of our information technology companies in the mechanized mine stage and automated mine stage, only a small number of coal mining companies are into stage of Smart Mine.

The construction of Smart Mine is to improve the efficiency of mine production and operation, fundamentally ensure the safe production of coal mine enterprises, promote the integration of the coal mine enterprise upper and lower systems, and strengthen the management system of coal mine enterprises, avoiding the unclear responsibility of safety accidents and ensuring the security of system data transmission realizes the sharing and information sharing of production and operation of coal mine enterprises, so that the data generated by each subsystem plays the most important role. Reduce the occupation of personnel, achieve unattended operation in a dangerous environment, establish a new mine production management mode, and achieve high efficiency and high safety performance for coal mining enterprises. With the continuous deepening of the reform of coal enterprises, the level of informatization of coal mine enterprises is also getting higher and higher. Smart Mine can realize the application of smart information technology, so that the entire system of mines has independent thinking, reaction and execution capabilities, and realizes comprehensive information of human-machines. Integration and responsiveness minimizes human factors and provides support for business managers in production management. In the end, the mine will achieve safe, green and efficient mining, and achieve concept innovation, system innovation, management innovation and technological innovation.

2 Smart Mine Development Path and Key Technologies under Construction

China's smart coal unmanned mining technology has entered the smart working face and driving face stage since 2010 (1.0 era), and is currently in the process of smart of the whole mine (2.0 era), and will eventually enter the smart of mining technology subversion. (3.0 era), to achieve the goal of safe and efficient coal unmanned mining.

2.1 Smart working face and driving face stage——1.0 era

In the smart working face and driving face (1.0 era), the smart mining mode of "smart control + remote intervention" was put forward, and the development of fully mechanized mining equipment, smart mining, accurate positioning and navigation, accurate detection of geological information et al. Building smart remote operation technology platform to realize smart mine working face. The following are the key technologies for Smart mine 1.0:

Smart mining face system: Smart fully mechanized mining face control system, realize automatic control of coal mining operation and remote control; Improve the technology of coal cutting machine memory cutting, hydraulic bracket with machine automation, automatic face straightening et al. Establish monitoring center along the slot or ground to realize on-site/concentrated/remote three-level network management of the equipment. The system can automatically control the production capacity of the shearer according to the load of the transportation system; realize the coal mining of mobile equipment through wireless network coverage. The reliable communication under the working environment, the combination of video, voice and data, solves the communication bottleneck of the whole working face, and automatically tracks and monitors the video of the coal cutting process;

Smart rapid driving system: Smart coal roadway, rock roadway, smart rapid driving, drilling and bolting combined support technology, smart advanced detection technology, roadway driving smart control and other technologies to solve the problem of alternate mining and driving, to achieve the lack of people and even unmanned mining face.

Downhole precision positioning navigation system: The technical basis of the unmanned working face is high-speed underground communication system and high-precision underground positioning and navigation system, which can accurately collect information such as safety, production and management required at any place and at any time, and ensure the timeliness of information. The software platform of the equipment positioning system such as the unmanned working face shearer is formed by the software platform of high-precision electronic map and the secondary development technology of GIS.

Accurate detection of geological information system: According to the three-dimensional contour of the working face environment obtained by laser scanning, a dynamic three-dimensional modeling technique is used to establish a dynamic three-dimensional model of the working face environment. It is necessary to always grasp the real-time position, attitude and working conditions of all kinds of fully mechanized mining equipment under the working environment, in order to give an operable mining guidance under the comprehensive analysis of the overall working environment. It is required to be able to fuse the position and posture of the equipment, the working condition information and the three-dimensional model of the fully mechanized mining equipment to obtain the dynamic equipment simulation model, and then unify the environment and equipment, and finally completely reproduce the state of the working face in the computer.

Hazard source smart prevention and control early warning and smart decision system: The hazard source smart early warning and disaster mitigation system is based on risk warning. Through real-time online monitoring of different types of hazard sources, the hazard source risk index evaluation algorithm is used to conduct real-time online assessment of the risk of disasters in various mine areas to determine the risk, type, rating and solution. Through the deployment of various types of sensors in the area where the energy release type and the constrained failure type hazard source are likely to occur in the underground, real-time monitoring, analysis and uploading of the hazard indicators of various hazard sources can be realized. Real-time smart analysis of the risk level of the hazard source by using the hazard source disaster mechanism, trigger condition criteria, mine operating conditions and hazard factors monitoring index values that have been

mastered, judging the type and level of risk, and conducting downhole sound and light alarms, online in-situ warning.

2.2 Smart of the whole mine——2.0 era

The 2.0 era is an era of information interconnection and inter-communication of the entire mine, visualization of the entire mine, smart decision-making and automatic operation. From "the smart of a working face" to the " smart of the entire mining system", the smart of the entire mine has time and space services. The characteristics of integration and command and decision-making, and finally the transformation from the Internet of Everything to the Connection of All Things. The 2.0 era includes the following key technology systems:

Smart mine ventilation, drainage and other auxiliary production systems: Smart ventilation, transportation and other ancillary production systems provide a guarantee for the continuous and stable production of the working face.

Mine full station equipment facility health smart management system: Equipment prediction and health management technology have received extensive attention in recent years, mainly in the military, aerospace and other fields began to carry out specific research. For the large-scale electromechanical equipment of coal mines, the characteristics of some simple faults are mainly studied. The complex fault characteristics of the entire electromechanical system are still in the embryonic stage. The main process and content of health management is the management and health maintenance of the whole life cycle of large mechanical systems, including the establishment of system health indicators, inspection and testing, health evaluation and health recovery. The main methods and means for carrying out the health management of large-scale mechanical systems include various inspection methods, condition monitoring, fault diagnosis, health assessment, residual life prediction and other technical methods, as well as maintenance, maintenance, repair and transformation.

Mine ecological construction smart system: In order to minimize the impact of coal mining on the surface ecological environment, the mine ecological reengineering system, namely the ecological system reconstruction technology of pre-mining prevention and control, in-mining control, post-mining treatment, and the repeated restoration of the secondary ecosystem restoration technology . Before the coal seam mining, the surface ecological environment will be protected from wind and sand, and the ecological environment will be able to resist the coal seam mining impact, and the mine ecological environment self-protection function will be enhanced. In the process of coal mining, the green mining technology based on the adaptive mining technology of coal resources should be innovated to minimize the impact of coal resources mining on the surface ecological environment. Land reclamation is carried out after coal mining to restore and enhance the surface ecological environment. When the mining of the lower coal seam causes the influence of repeated mining on the surface ecological environment, the surface ecological environment should be repaired timely to prevent the damage of repeated mining on the surface ecology.

Smart coal mine centralized management system: Integrate research results, build a smart coal mine system based on cloud computing data center, with safety management and control platform and four-dimensional integrated management platform as the core, effectively integrate and centralize all subsystems of the mine, to guide and regulate the operation of various production systems and links, and to build a centralized management system for smart coal mines.

2.3 The subversion of smart mining technology——3.0 era

With the development of the times, the emergence of the Internet, artificial smart, cloud computing, big data, new technology, these new technologies are combined with the traditional coal mining industry, the formation of new technology, new thinking, new ideas of smart mine. The formation of Smart Mine will eventually break the restrictions of the traditional mining industry and change the mining methods of traditional coal mine, such as coal gasification, fluidized mining and direct underground coal power generation and other new mining modes, achieving unmanned and smart mining underground. Subvert the traditional mining mode, transportation mode and utilization mode of solid resource development; open up a new mining industry model, lead the technological revolution of mineral resources mining, realize the clean, efficient and eco-friendly development of deep mineral resources, and open up new space for economic growth; Deep in-situ liquefaction technology, deep in-situ gasification technology, and deep in-situ electro-chemical technology to complete the new mining mode of solid coal resources.

3 Smart Mine Construction Practice in China

With the increase in our coal mining smart technical aspects of R & D investment, to achieve a breakthrough, leading the direction of the coal industry in the international mining smart. Smart coal mining has been carried out in more than 40 mining areas, including Shendong Coal Group, Ningxia Coal Industry Group, China Coal Group, Shanxi Coal Chemical Group, Tongmei Coal Group, Jinmei Coal Group and Jizhong Energy Group. But strictly speaking, the smart working face under construction is in the stage of Smart Mine 1.0, and have not fully realized unmanned mining face. The following brief introduction to some of the smart working face representative.

Huangling Mining Group 1001 working face the first application of mechanized mining smart control system (SAM) to achieve the smart exploitation. Control system supporting the use of electro-hydraulic control system of hydraulic support (SAC type) and winning machine control system, the " unmanned operation, one-man patrol" Visualization smart remote intervention type mining, to " two people in the monitoring center of transportation lane in the working face visual remote intervention control, one person patrol in the working face" normalization run of results, monthly production of 170300 t, the annual production capacity of more than 2 million t, productivity increased by 25%, production workers decreased from 11 to 3 people, more than 7 million yuan savings in labor costs, the level of safety for a larger increase. The working site of the monitoring center of the transportation lane in the underground working face of Huangling Mine is shown in Figure 1.

Figure. 1. Roadway monitoring center under Huangling Mine (Li et al., 2019)

Shandong Energy Zaozhuang Mining Group Binhu Coal Mine 16108 working face, by SAC bracket electro-hydraulic control system, TDECS shearer memory cutting system and working face video monitoring system were adopted ,to achieve a fully automated under the thin seam mining conditions combined with smart exploitation of remote visualization intervention. By the electro-hydraulic control system of hydraulic support, shearer cutting system memory, a video monitoring system to collect data and face images uploaded to the monitoring center located in the roadway, the operator of the work face can be achieved in the monitoring center automatic operation with the machine, shearer cutting smart memory "one-click start and stop" and the remote control of the shearer brackets and all actions, the average monthly production of coal amounted to 105 000 t, compared to non-smart working face coal produced more than 45 000 t, and the production staff of the working face was operated by the original two coal mining drivers, six bracket workers sectional machine pull frame were turned into one person for remote control, and the two people were patrolled. The annual labor cost was 1.152 million yuan, and the production level was safe. Significantly increased.

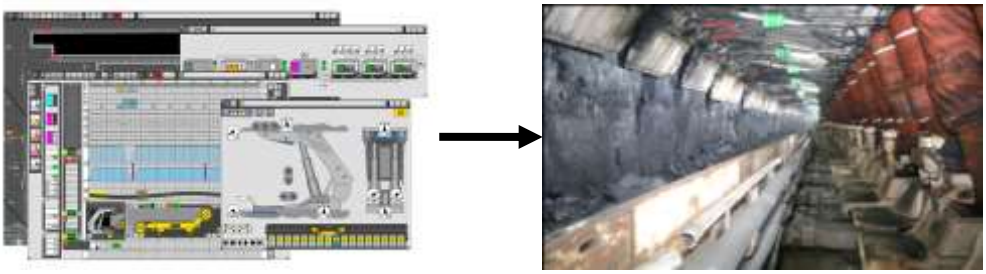

Figure. 2. Shearer memory cutting and Remote control shearer operation of Binhu Coal Mine (Wei et al., 2019)

Shendong Shangwan Coal Mine 8.8 meters of fully mechanized mining face among the highest in the world face, the face's hydraulic support, transport aircraft, transport vehicles and auxiliary transport adit et al. create more domestic and world record. The working face adopts domestic equipment, introduces digital and smart technology, and develops the travel system of high speed and high reliability heavy load shearer with 8.8m primary mining full height. In China, 3D printing technology was used for the first time to optimize the profile and structure of the sprocket wheel, and improve the machining accuracy, bearing capacity and reliability of the walking wheel. There are 128 sets of 8.8m electro-hydraulic control two-column shield hydraulic supports applied in shangwan coal mine. In addition to the highest support height in the world, this set of hydraulic supports can improve the working efficiency of Shendong Shangwan coal mine by more than 85%, reduce the cost by 30%, and increase the recovery rate of resources by 30%.

Tongxin Coal Mine adopts smart control system top coal caving face, built and successfully commissioned the first smart fully mechanized caving face in the 8202 fully mechanized caving face of the mine. To achieve a safe, efficient, low cost mining, resource recovery rate of more than 2.35%. The energy consumption per ton of coal is reduced by 5%, and the economic, safety and social benefits are very significant. The original fully mechanized mining face needs 20 workers per shift, but now only 10 people, the efficiency has been increased by 50%, reducing the labor intensity of workers. The equipment on the working face can cut coal automatically according to the program setting, and the support can be moved and sprayed automatically. The operator sitting in the monitoring center can carry out the full-automatic start-stop control on the equipment on the working face.

4 Technical Difficulties in the Construction of Smart Mine

According to the construction practice of Smart Mine in China, the level of automation and smart technology in coal mines is still low, the reliability of mining equipment needs to be enhanced, and the visualization technology in the harsh environment is urgently needed to be solved. Therefore, simulating human sensory and brain operations is a key factor in achieving smart unmanned mining. At present, some key smart technologies are still in the research stage, which makes it impossible to realize unmanned mining in some complicated working faces. In the construction process of smart mines, the following technical problems are mainly faced:

Coal rock interface identification technology and automatic height adjustment technology: To obtain the maximum recovery rate and reduce energy waste, the need to ensure cutting in the roof and floor area boundary, and to try to ensure smooth floor. Automatic navigation technology combined with geographic information system can preliminary to three-dimensional positioning of working face, but the geographic information system can not accurately obtain the dynamic Angle of coal seam and the coal and rock interface information, only through the recognition of coal and rock interface and real-time measurement of dynamic Angle of coal seam, can precisely control roller automatically adjustable high, make the cutting area and coal seam occurrence is consistent information.

Communication optimization technology: At present, the data transmission mainly adopts wire transmission and cable, but the disadvantage is that there are many fault points and it is difficult to maintain. Therefore, according to the requirements of data transmission, wireless transmission is adopted to realize the transmission and monitoring of all kinds of data.

About the high precision, high stability sensor technology: Although the sensors in use at present can realize the monitoring and collection of relevant data in the production process, there are still problems in the aspects of accuracy, transmission speed, data collection amount, anti-interference ability, seismic resistance, waterproof, dust penetration and stability, which restrict the further development of smart mines to different degrees.

The technology of information exchange between systems, fault self-diagnosis and autonomous decision making：At present smart mining technology in smart perception, independent decision-making and other smart level lower, it is unable to complete the equipment adaptive adjustment according to the geological changes of the smart fully mechanized mining face in the coal mining process. Further exploration should be made in the aspects of smart detection, smart analysis and smart control technology research, so as to improve the smart perception, autonomous adaptation and smart control ability of the equipment，as well as the need for smart equipment failure from the category of the fault, the fault location, on the way to explore and realize automatic judgement and processing of the system software.

Production continuity guarantee technology: In order to ensure the continuity of the production of fully mechanized mining face, it is necessary to carry out reasonable and orderly monitoring of each link and smartly solve some unexpected problems. Such as conveyor balance control technology, anti-collision technology, monitoring of mine pressure, scraper chain tension, conveyor joint strength, porosity, gas, fire, roof fooling et al.

5 Summary

The development of Smart Mine is a process of continuous improvement. The overall goal of the Smart Mine is divided into three development stages, from the smart of the mining working face (1.0 era) to the smart of the whole mine (2.0 era); Finally, the mining technology subversion of the smart mine (3.0 era), and ultimately achieve mine safety,

green, efficient, unmanned mining, to achieve concept innovation, system innovation, management innovation, technological innovation.

The state and coal enterprises have attached great importance and strong support to the construction of Smart Mine, and carried out a large number of theoretical and practical explorations and practices; the current coal smart unmanned mining is still in the comprehensive mining automation combined with visual remote intervention the semi-automatic 1.0 era; By the end of 2018, 145 fully mechanized mining faces in more than 40 mining areas have been implemented for smart mining.

However, there are still many unresolved problems in the realization of Smart Mine; there are low conversion rates of scientific and technological achievements, practical application of heavy concept propaganda, and poor adaptability to various complex geological conditions. At present, the distance from the real realization of smart, unmanned, and normalized applications is still far away, and it is still necessary to make great efforts in management concepts, investment, and R&D team building. With the development of related basic industries such as advanced manufacturing, sensing, computing science and technology, and with the continuous improvement of technical conditions, the only way for smart mine to make the coal mine unmanned, improve efficiency and green safety will be achieved.

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