Research on Automatic Spray Equipment of Thin Spray Support Technology for New Material in Coal Mine Roadway

Huihui Dong¹, Andong Lou², Jianguo Zhu², and Fusong Min¹

¹Nanjing Coal Science & Technology Research Co., Ltd., Nanjing, Jiangsu 210018, China
²Luoyang Mining Machinery Engineering Design and Research Institute Co., Ltd., Luoyang, Henan 471039, China
*Corresponding author and e-mail: Andong Lou, citichma_louad@163.com

Abstract: Based on a new type of non-reactive polymer powder material for thin spray-on support technology in coal mine roadway, an automatic spray equipment for coal mine roadway thin spray-on support is designed and developed. It has kinds of movements and motion trajectories. This paper introduces the technological basis and working principle of the equipment, design basis, and overall system composition of the equipment, which includes: mechanical system, hydraulic system, and control system. Compared with the concrete spraying technology, the thin spray-on technology can reduce the material transportation volume by more than 90%, significantly reduce the labor intensity of workers, improve the construction efficiency and the construction environment. It is an ideal choice for future support and construction of underground roadways.

1. Introduction
The development of clean, safe and fast support technology has become an important part of efficient and safe production in coal mines. With the development of thin spray material and thin spray support technology, more and more coal mines accept it. In the construction of large-scale mine roadways and large cross-sections tunnels, there are big problems in the existing construction technology and equipment. With the requirement of large amount of construction and high efficiency of construction, the length of the roadway for thin spray construction in some coal mines is up to km, part of the height is large, making it difficult for workers to implement, and the quality of spraying cannot be guaranteed. Ordinary thin spray construction technology and equipment have been unable to meet the construction requirements. The existing equipment is mechanized and has a low automation level, which is difficult to meet the requirements of high-speed tunneling. It requires thin spray equipment with a higher level of technology and automation.

Based on the thin-spray material roadway thin spray support technology, the research and development of automatic spray equipment for thin spray support in the roadway is developed. The corresponding products and results can also be applied to the support construction sites such as tunnels, which has great market and social significance.

2. The Process of Thin Spray Support Technology and Working Principle of Equipment
In order to ensure the cleanliness of the spray support environment, the process is based on wet spraying. The thin spray automatic equipment is developed on the premise of basically realizing dust-free spray support.
Based on the research of the basic properties of thin spray materials, the optimal design of thin spray parameter matching was carried out. The spray arm adopts a swinging spray structure of the extension to improve the flexibility of spray construction; The supporting automatic control technology mainly includes automatic extension and contraction of the spray arm, distance detection and identification, pressure and flow control of spraying materials, liquid and gas, so as to improve the spray automation, Control of the positioning accuracy and uniformity of the spray layer. On the premise of meeting the functional requirements, the structure of the spray arm is optimized, and the overall lightweight design is performed to improve the flexibility of the spray arm.

Referring to the working principle, control scheme and related software of industrial spraying robot, there are mainly technologies based on dynamics control, trajectory planning, vibration suppression, electromechanical coupling and other technologies for the spray equipment, especially its related control algorithm and theory, software design to control the spraying trajectory and path of spray gun scientifically and reasonably and a comprehensive and scientific optimization is carried out from both soft and hard aspects to control the spraying pressure, flow, time, spraying distance and other related technologies. In order to reduce the waste of spraying materials and improve the uniformity of spray thickness and film-forming quality.

3. Design Basis
According to the analysis of the thin material spray process at the construction site of the roadway, the overall mechanical structure of the thin spray automatic equipment is determined, obtaining the size of the equipment and basic movement form of the spray arm for construction, and realizing the boom pitching (range 90°) Swing (range 240°), arm extension and spray gun attitude adjustment. The spray gun is equipped with two measurement sensors, which can sense the relative distance between the spray gun head and the wall of the roadway when the equipment is working, so as to maintain the stability of the spray distance and ensure the spray continuity and uniformity.

In order to adapt to the complex roadway conditions in coal mine, the walking mechanism of the thin spray equipment adopts a small crawler chassis to ensure good passability and flexibility of the equipment; the chassis is equipped with sensors to collect data and information of the surrounding environment of the walking mechanism, which has the function of automatically sensing and keeping straight-line walking when the direction of advance is unobstructed; Through the optimization of software and hardware system, it can ensure that the automatic construction operation of the spray arm is compatible with the control strategy, and scientifically control the movement trajectory of the spray gun and the spraying pressure and flow rate, etc., so as to ensure the film-forming quality and construction efficiency of thin spraying materials. The specific automatic spraying operation scenario is shown in Figure 1.

4. The Operation Process of the Thin Spray Automatic Equipment
1. The equipment enters the working area of the roadway through manual remote control; the equipment should be arranged in the middle of the roadway as far as possible, parallel to the roadway, and followed by the equipment of the thin material mixing system;
2. The power device is connected to take power for power supply, the thin material mixing and pumping system is connected to the water supply (air supply) source; each device is started, the spray arm is rotated and extended at the same time, and the relative distance between the nozzle and the wall of the roadway through the sensor to prepare for operation;
3. The equipment of the thin material mixing and pumping system is started, filling the thin material, adding water according to the process, after the mixing is completed, pump the mix material to the spray pipe to the nozzle, and the thin spray equipment begins to swing the arm to perform the spraying operation;
4. According to the requirement of spray-film thickness, the spray arm sets the swinging speed or the spray period and times. The spray arm automatically adjusts the extension amount according to the distance between the nozzle and the roadway wall, and carries out spraying in the arch roadway;
5. After the spray of one section of the arched roadway is completed, the spray is stopped and the spray arm is shortened; the equipment automatically moves straight to the next operation position and
continues the next spray operation process;

6. After the spray operation of the entire roadway is completed, the spray arm is contracted, rotated, and folded to the initial position for easy transportation and parking. The working process is shown in Figure 1.

![Figure 1](image1.jpg)

**Figure 1.** The automatic spraying operation scenario and working process

5. **The Composition of Equipment System**
The thin spray automatic equipment is composed of multiple systems including mechanical structure system (chassis+arm), spraying system, power system, hydraulic system, sensing and electro-hydraulic proportional control system. Each system is based on the coal safety explosion-proof design principle and constitutes a block diagram as shown in Figure 2.

![Figure 2](image2.jpg)

**Figure 2.** Constitutes a block diagram
5.1. Mechanical System and Working Space Range
The main body of the machine consists of the arm assembly, the lower body assembly, the upper body assembly, and the hydraulic drive mechanism. The upper body assembly is equipped with power system (electric motor), electrical control system, wireless communication system, hydraulic system and lighting system. the mechanical structure and working space range shown in Figure 3.

![Figure 3. Mechanical system and working space range](image)

In order to improve the road passability and walking stability of the equipment under various complex road conditions, the walking mechanism adopts the crawler structure, which is driven by two hydraulic rotary motors with brakes. When the speeds of the two tracks are the same, the equipment can move forward or backward; when the speeds of the two tracks are different, the equipment achieves steering movement.

5.2. Power System
The power system is the power source of equipment to walk and work. Considering the environment and technical requirements of roadway operation site, the scheme adopts MA certified K3 explosion-proof motor drive.

The power source is taken from the underground power grid. The available voltage and frequency are 1140 / 660V, 50Hz. The motor starts directly, and the starting switch is equipped with a phase sequence protection device, so that the motor has the correct direction of rotation and is not affected by the phase sequence at the power output end of the power supply. The power system is mainly composed of motor installation, cooling system, protection system and partition assembly.

5.3. Hydraulic System
The hydraulic system is the driving source for each actuator, such as the rotation and extension of the spray arm, chassis travel. It is mainly composed of load sensitive variable piston pump, load-sensitive electro-hydraulic proportional directional valve, double-acting hydraulic cylinder, hydraulic rotary motor, walking motor, center rotary joint, safety valve, balance valve, solenoid valve and other hydraulic components. The whole hydraulic system can be divided into two parts: the main hydraulic circuit and the load feedback hydraulic circuit. The main pump equipped with the hydraulic system adopts the load sensitive variable pump, the control technology combining the load sensing and the independent flow distribution system independent of the load pressure is used. The high pressure load sensing proportional multi-way valve and LUDV proportional multi-way valve are selected as The control core components of the system make the output flow of the pump always meet the needs of the load, and have the advantages of good start-up performance and operating performance, energy saving and small system heating.
5.4. Electrical Control System

The electrical control system is mainly composed of motor start stop + phase sequence protection circuit, remote control system, controller, rectifier power supply, alarm circuit, lighting circuit and explosion-proof electrical cabinet. The composition diagram of the control system is shown in Figure 4.

![Figure 4. The composition diagram of the control system](image)

All cable outlets of explosion-proof electrical cabinets use cable waterproof explosion-proof connectors and explosion-proof heavy-duty connectors. The entire explosion-proof control cabinet is fully enclosed, which can be effectively explosion-proof, waterproof, and dust-proof. Explosion-proof remote controllers and controllers are reliable components, with a wide ambient operating temperature and an IP65 protection level, fully adaptable to harsh working conditions. The electrical components in explosion-proof electrical cabinets are mainly imported brands with stable performance. The control loop power supply uses DC24V, which can effectively prevent electric shock accidents. The equipment is equipped with high-power LED work lights to ensure good illumination at the work site.

The hydraulic system is controlled by the electro-hydraulic proportional system based on the pulse width modulation. The basic components of the electro-hydraulic proportional control system include the control handle, controller, pulse width modulation (PWM) drive circuit, electro-hydraulic proportional valve and actuator. The control signal is generated by the remote control handle to control the output pressure of the electro-hydraulic proportional pilot valve, so as to control the position of the valve core of the main reversing valve, realize the control of the working speed of the working hydraulic cylinder.

The electro-hydraulic proportional valve is controlled by PWM, and the average current flowing through the proportional solenoid coil is adjusted by changing the duty ratio of PWM signal, so as to reduce friction, hysteresis and dead zone of the solenoid, and improve the response speed of the electro-hydraulic proportional valve.

In order to ensure that the control system of the equipment has good response characteristics and module expandability, the communication system of the equipment adopts the CAN bus communication mode, and the entire communication system integrating the equipment is established by using infrared remote control technology.

6. Conclusion

Carrying out research on thin-spray automatic spraying technology and equipment can solve the need for large workloads, closed construction demand of large roadway, and improve construction efficiency; improve the working environment of spray support, protect the health of workers; and improve the quality of spray-spray support. Reduce support costs; give full play to the performance and advantages of thin spray material, greatly reduce the labor intensity of workers and human factors on the spray quality to achieve standardization and consistency of spray. Automated thin spray
technology and equipment can further promote the application of thin spray materials in coal mines, and at the same time promote the rapid development of coal mines and the advancement of efficient and safe green mining technology.

7. Acknowledgement
Support from Special Key Projects of Science and Technology Innovation and Venture Capital of China Coal Technology & Engineering Group Corp (Grant No. 2018-2-ZD002) is acknowledged.

8. References
[1] L. Lacerda, M. Rispin. Current ground support membrane applications in north American underground mines [C]. 2002 SME Annual Meeting, Feb. 25-27, Phoenix, Arizona.
[2] Lacerda, L. “GSM internal test report,” Bullfrogmine, Lacminerals, Beatty, NV, 1994.
[3] Thibodeau, D. “Masterseal Trial” Barrick gold strike underground division report, Elko, NV, 2000.
[4] Atkar P N, Greenfield A, Conner D C, et al. Uniform coverage of automotive surface patches [J]. International Journal of Robotics Research, 2005, 24 (11): 883 – 898.
[5] Li Yunjiang et al. Mechanical structure design and research of shotcreting robot. Mining machinery, 1999 (8).
[6] Li shican, Xun Qiqiang, Ma Chunhong. Study on field application and improvement of push chain concrete shotcreting machine [J]. Shandong coal technology, 2015 (9): 95-96.