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Research Progress of Temporary Support Equipment for Fully Mechanized Excavation Roadway

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Abstract: With the acceleration of the iteration speed of the fully-mechanized excavation machine, the problem of 'imbalance between excavation and support' in the fully-mechanized excavation roadway is becoming more and more serious. Temporary support is the key par t of roadway excavation and the key to determining the safe and efficient production of coal mines. The development and research of temporary support is the key direction at present. This paper expounds the technical development process of temporary support from traditional support to the mechanized period and finally to the intelligent period. Common temporary support equipment, such as front beam temporary support, single hydraulic prop temporary support, step self-moving temporary support and airborne temporary support, was analyzed the advantages and disadvantages of various types of equipment. According to the current phenomenon of "mining imbalance" in coal mines, the policy of "equal emphasis on mining and tunneling first" should be implemented, and corresponding measures should be taken, such as developing a coal roadway tunneling robot system to integrate "excavation," "branch," "transportation" and "communication," integrating equipment with the Internet of Things, 5G communication, artificial intelligence and so on to promote the intelligence of temporary support equipment.

Keywords: Comprehensive excavation roadway; Temporary support; Intelligent equipment

As the main energy source in China, the safe and efficient production of coal is an important cornerstone of national energy security. Benefit from the continuous contribution of key coal-producing areas such as Shanxi, Shaanxi, Inner Mongolia and Xinjiang. China's coal production reached 4.76 billion tons in 2024.Year-on-year growth of 1.3%. China's coal mines are mainly underground mining, and a large number of roadways need to be excavated underground for about 13000km per year Huge, ranking first in the world. Coal mine production follows the basic procedure of "equal emphasis on mining and tunneling first." The rapid and safe tunneling of the roadway is the key link to ensure

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the normal replacement and production efficiency of the coal mining face. However, in actual production, there is a prominent contradiction of ‘mining imbalance’. Tunneling efficiency has become a bottleneck restricting the safe and efficient production of the entire coal mine.

In this context, improving the speed of roadway excavation has become an urgent need to solve the “mining imbalance” and ensure the continuous and stable production of coal mines. The tunneling speed of roadway is affected by many factors, including tunneling technology and equipment performance, support form selection, support parameter design and support construction technology and equipment. In the roadway excavation operation cycle, there is a critical and dangerous roof exposure period from the comprehensive excavation to the installation of permanent support. In order to ensure the safety of operators, improve the efficiency of support and ultimately accelerate the whole process of roadway formation, safe, fast and effective temporary support technology and equipment have become an indispensable core component of modern rapid excavation system.

According to the statistical data released by the Ministry of Emergency Management of China and the State Coal Mine Safety Supervision Bureau. According to incomplete statistics, there were 109 roof accidents in coal mines in China from 2019 to 2024, with 168 deaths in roof accidents. Among them, head-on accidents also account for a significant proportion. The problem of ‘ imbalance between excavation and support ‘ in fully mechanized excavation roadway still exists, so the temporary support of fully mechanized excavation roadway is still a key technology to be solved urgently. In recent years, many studies have been carried out on the temporary support of fully mechanized excavation roadway, and many scholars have developed a variety of temporary support equipment. Lay the foundation for efficient coal production(Yue Z W et al., 2023).

1 The Development Process of Temporary Support Technology

1.1 Traditional Support Period

Wood support technology. The structural forms of wood support are mainly divided into rectangular wood support, trapezoidal wood support and arched wood support. Temporary support roadway surrounding rock and the use of brush asphalt, tar anti-corrosion treatment. Wooden support is an important supporting technology in the history of mining industry, which promoted the development of early underground resources.

Liu Chengen et al(Liu C E, 1966)first proposed a timber support method for high caving areas. The ‘ high caving area ‘ is defined as the area where the roof fall height of the roadway is more than 3-4m.In this paper, the author compares the advantages and disadvantages of the traditional wood crib method and the laminated wood shed method. The former consumes a large amount of materials and the construction is slow, while the latter saves materials but has high technical requirements. The limitation of the two is that the stability of the roadway is difficult to last. Han et al(Han Z X & Qiao Y, 1995) focused on the optimization design of the wooden stack support structure. In view of the problem of rising wood cost and deteriorating geological conditions in mine support, the optimization of wood support design and erection method is proposed to improve the utilization rate of wood. The choice of materials gives priority to the use of wide wood cubes, high compressive strength wood, and pioneered a variety of contact surface combinations such as wood block stacking wood blocks, wood block stacking wood cubes, and wood block stacking wood cubes.

It provides a quantifiable engineering solution for the modern improvement of traditional support technology, and the research emphasizes the significant improvement of wood performance utilization from conventional 20% through scientific design. He Shengjun(He S J et al., 1998)represents the new direction of technology development, and developed a bamboo fiber composite mining support. This study innovatively uses bamboo as raw material, and the new scaffold made by multiple processes shows significant advantages. The bearing capacity is 214.10 kN, with elastic recovery ability, light weight, low cost and service life of more than 6 years.

1.2 Mechanized Support Period

With the popularization rate of comprehensive roadheader in the 1990s exceeding 60%, the speed of 8m per day of traditional wood support is seriously mismatched with the speed of 15m per day of roadheader in the same period, which restricts the continuity of excavation and support. In the 2010 GB25974.1-2010 coal mine hydraulic support, it is clearly required that the initial support force of the support should reach more than 95% of the rated value when it leaves the factory. This has promoted the transformation of support equipment to mechanization. During this period, the single hydraulic prop and Π beam became the mainstream temporary support form as temporary support. Taking the II3118 working face of Shitai Coal Mine as the background, Shao Changqing(Shao C Q, 2010)adopts the active + passive support system. The active support is 10 Φ20 multiplied by 2200mm high strength screw steel bolts(Row spacing 800 multiplied by800mm)+ 2M-shaped steel belt and 2 anchor cables(Staggered arrangement, length 5.4 m, anchorage section 1.9m, suspension section 3.0m)The passive support is a Π shaped beam with a single hydraulic prop (one beam and three columns, initial support force more than70kN). It can effectively control the roof deformation, ensure the requirements of roadway construction, and provide a reliable guarantee for the safe production of II3118 working face in Shitai Coal Mine.

1.3 Intelligent Support Period

With the increase of mining depth, the working performance, roof stability and strength of temporary support equipment will be affected, and the probability of roof collapse will be improved. Therefore, higher requirements are put forward for the roof control ability of temporary support equipment and the integration development of industrialization and informatization in a wider range, deeper degree and higher level is required. The temporary support robot in the key research and development catalogue of coal mine robots issued by the National Mine Safety Supervision Bureau in 2019 requires the development of intelligent perception of surrounding rock state of tunneling roadway, autonomous mobile positioning temporary support robot, with the functions of adaptive control of support force, adaptive control of support attitude, multi-frame coordination and remote intervention, to ensure the timely and reliable temporary support of tunneling roadway and improve the efficiency and safety of tunneling. Since then, China ‘s temporary support technology has entered the intelligent period.

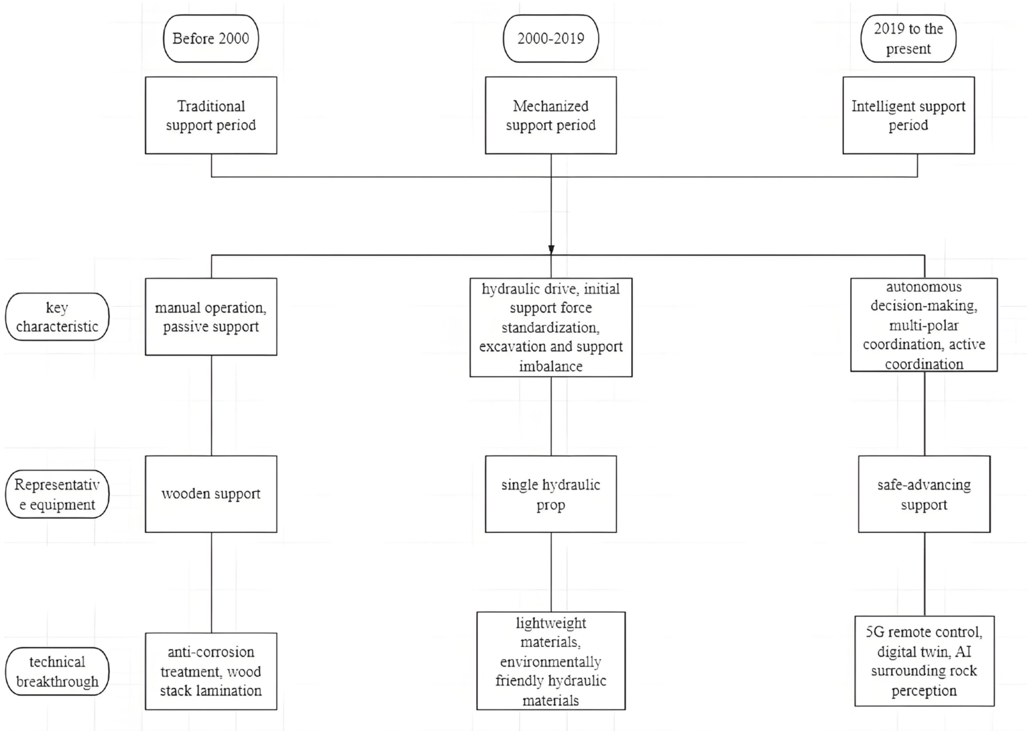

Figure 1 Schematic diagram of the development process of temporary support technology

2 Research Status of Temporary Support in Fully Mechanized Excavation Roadway

Temporary support of fully mechanized excavation roadway refers to the temporary safety support measures taken before the completion of permanent support construction in order to ensure the stability of working face and surrounding rock during the excavation of fully mechanized excavation roadway. Its purpose is to prevent the surrounding rock from loosening, falling or deformation after roadway excavation and before permanent support installation, so as to ensure the safety of construction personnel and equipment. The temporary support has the ability to control the deformation of surrounding rock and prevent roof fall, rib spalling and other accidents. It provides safe working space for permanent support construction.

At present, the common forms of temporary support for fully mechanized excavation roadway include front beam temporary support, single hydraulic prop temporary support, step self-moving temporary support and airborne temporary support.

2.1 Front Beam Equipment

The temporary support of the front exploration beam usually adopts two steel pipes. Each steel pipe is attached with two ring suspension points, and each ring is linked to the bolt on the roof through the nut. In use, the ring (lifting ring) is first installed on the bolt, and the steel pipe is worn to the end. The connected mesh is laid on the steel pipe, and two wooden boards are inserted between the steel pipe and the mesh for support. Personnel perform permanent support and other operations under the cover of this temporary support(Wang W Z, 2021). The temporary support equipment of the front beam is shown in Table 1.

In terms of structural optimization, Nie Shoujiang(Nie S J, 2022)[10]developed an arc-shaped front beam detection system based on arched roadway sections to solve the problems of support failure and risk of empty roof operation in traditional temporary support (such as lifting ring and pipe erection) in coal mine roadway excavation. The traditional straight beam front beam is improved to the arc front beam for structural optimization, which is more suitable for the arch roadway structure and improves the support stability. Through the structural design of the top arc frame and the bottom leg, the initial support force is ensured and the thrust structure advantage is given to improve the bearing performance. The static analysis of the curved front beam is carried out. The simplified model shows that the stress concentration at the center D point is shown in Fig.2, and the analysis safety factor meets the standards of plastic and brittle materials, And the critical load is solved by MATLAB, which shows that the actual safety force is less than or equal to 269KN and the digital analysis of Pro / E modeling shows that there is no risk of yield failure. This equipment is suitable for the support of arch roadway. Compared with the straight beam structure, the bearing capacity of the arc front beam is increased by about 30%, and the deformation of the support is reduced. Li Junjun(Li J J, 2023) took Sangou Xindu Coal Industry as the background to solve the temporary support problem of non-mechanized tunneling roadway. The optimization of double U-shaped steel bar + square steel composite structure is adopted to improve the overall stiffness and bearing capacity of the front beam, and effectively solve the problem of empty roof in 1501 machine roadway. This equipment is practical for the construction of non-mechanized scenes. After adopting the new structure, the support time is shortened by 40% and the stability is improved. However, no long-term durability test was performed. Taking Changcun Coal Mine as the background, Lu qingxu et al(Lü X Q et al., 2021).developed the installation process of the front beam of the side to solve the problem of rib spalling in the excavation process of soft media layer. Optimize the front beam of the side to ensure that it can support the rock mass of the side in time to prevent collapse. This equipment is suitable for soft coal seam. After the new equipment is adopted, the spalling accident is reduced by 60%, and the support effect is good.

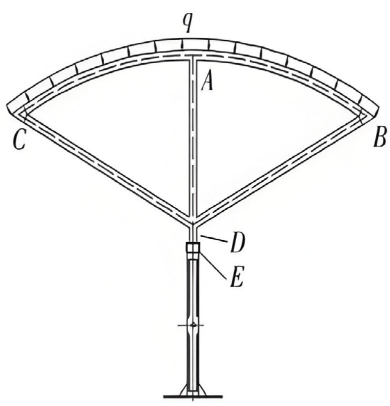

Figure 2 Simplified model of curved front beam(Nie S J, 2022)

In terms of parameter optimization, Liu Jie solved the problem of working face spalling in steeply inclined coal seams. The parameters of the spacing and installation angle of the front beam are optimized, and the connection mode between the fixed ring sleeve and the fixed rod is optimized. This equipment is suitable for thin coal seams with coal seam dip angle more than 45° and coal seam thickness less than 1.5m. After parameter optimization, the spalling rate decreased by 50%.

In terms of material innovation, Wei Chuisheng(Wei C S, 2021) improved the traditional ‘front beam and wood back plate’ support method based on the background of Cheji Coal Mine and used the locking mechanism, that is, the middle perforation of the back plate and the mechanical locking of the front beam to eliminate the balance adjustment between the components. As shown in Figure 3,a temporary support scheme is designed in this paper. The number of front detection beams is different under different roadway widths. The front detection beams are vertical and parallel to each other. Each front detection beam is arranged to use at least two lifting rings, and the spacing of lifting rings is more than 600mm. This equipment is suitable for manual support scenarios. After the new equipment is used, the construction efficiency is doubled and the wood consumption is reduced.

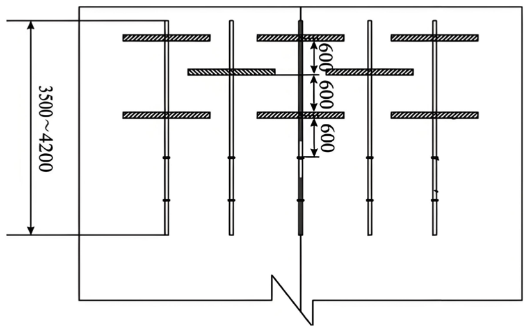

Figure 3 Top view of temporary support scheme(Wei C S, 2021)

Table 1 Situation table of temporary support equipment for the front beam

Time	Author	Research method	Innovation	Effect
2022	Nie Shoujiang	finite element analysis	Arc beam modeling and stress analysis	The bearing effect is increased by 30%.
2023	Li Junjun et al	structural designing of composites	Double U-shaped steel bar	Empty roof accidents down 90%
2021	Lü Qingxu	Structure-process collaborative optimization	The guide slide rail design is adopted in the side part.	80% reduction in rib spalling frequency
2022	Liu Jie	Parameter design, process verification	Fixed ring sleeve and rod integrated system	The spalling rate is reduced to less than 5%.
2021	Wei Chuisheng	Material substitution and process reengineering	Backing plate assembly	Single-cycle operation reduced to 15 minutes

Although the temporary support of the front exploration beam is simple and low cost, the shortcomings are obvious. Before the installation of the front exploration beam, a short empty roof operation is required, which increases the risk of roof fall. The front exploration beam equipment can only passively support the exposed roof and cannot actively apply preload, so it is difficult to control the early deformation of surrounding rock.

2.2 Single Hydraulic Prop Equipment

The single hydraulic prop is developed on the basis of the early wooden prop, and the working resistance of the liquid pressure is used to temporarily support the empty roof area of the roadway (Yue Z W et al., 2023). The equipment of single hydraulic prop is shown in Table 1.

In terms of structural optimization, Gao Xia(Gao X et al., 2013) and others responded to environmental protection requirements in 2013, using pure water as the working medium of the hydraulic system. The DW18-300/100 pure water single hydraulic prop with inner diameter of 100mm, working resistance of 300kN and maximum height of 1800mm was designed. The cylinder block was made of 27SiMn hot rolled seamless steel tube, and the inner surface was galvanized nickel alloy for equipment optimization. This equipment is suitable for mines with environmentally friendly media. The use of new equipment can avoid emulsion pollution, thereby reducing the risk of pollution. In 2014, Li Zhanliang et al(Li Z L et al., 2014).used Pro / E, MATLAB, ADAMS and other software to carry out three-dimensional modeling, dynamic simulation and dynamic analysis of the joint simulation due to the long development cycle of DWX type single hydraulic prop products, the great destructiveness of the test, and the difficulty of fault diagnosis. The design of the prop parts and the parametric adjustment, the parametric design of the prop structure and the dynamic analysis of the stress concentration and other damage factors. This equipment is suitable for high load support in complex geology, and the simulation results can be used to guide the design of pillars to adapt to different roadway pressure conditions. Using new equipment to reduce the cost of 30 % to reduce the destruction of physical experiments.

In terms of product research and development, Wang Xiujuan et al(Wang X J et al., 2019).in 2019 for ordinary single hydraulic prop quality, small working resistance, grouting height; aiming at the problems of high manufacturing cost and complex maintenance, the DWZ lightweight combined single hydraulic prop is developed by combining the advantages of piston and suspension props. This equipment is suitable for advanced support of mining roadway and scenes requiring rapid disassembly and frequent movement. The quality, grouting height and working resistance of different types of piston, DWX suspended and DWZ combined single hydraulic props are compared as shown in Figure 4. With the new equipment, the weight is reduced by 30% and the working resistance is increased by 15%. The final result of 50% improvement in maintenance efficiency is applied to Jining Mining Group. In 2011, Wang Weifeng et al(Wang W F, 2011).designed a light single hydraulic prop to solve the problem of temporary support in the heading face, optimize the construction process (rapid lifting) and simplify the structure. This equipment is suitable for heading face temporary support area and space restricted area. The handling efficiency is improved after the new equipment is adopted.

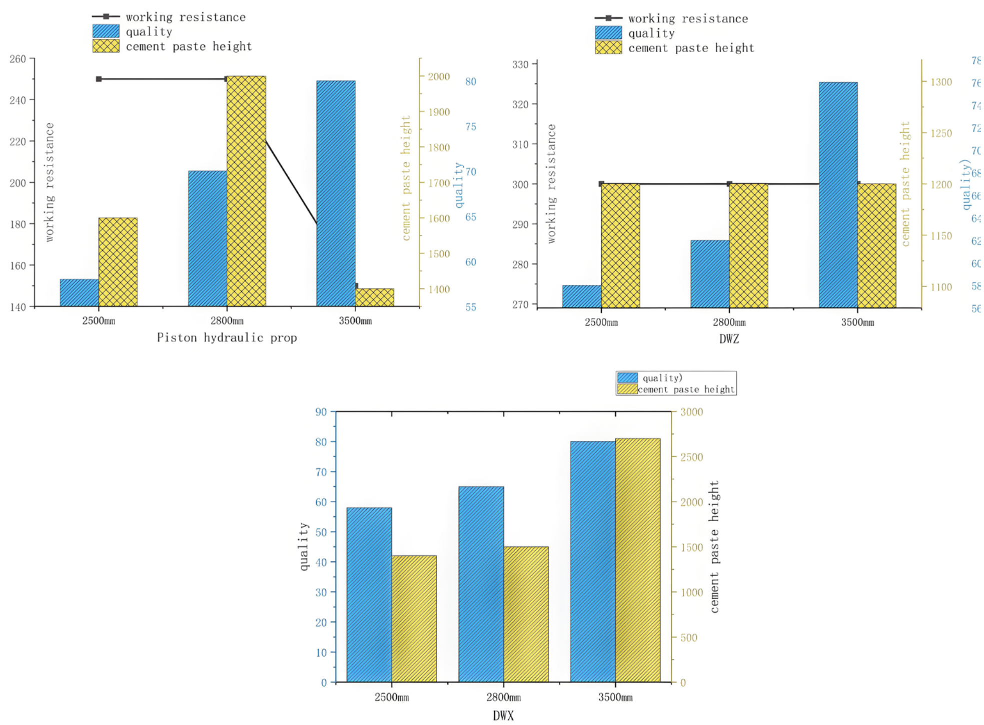

Figure 4　Comparison of parameters of different types of single hydraulic props

In terms of intelligent detection, Gao xuan(Yang X, 2019) combined the Internet of Things technology with the single hydraulic prop to develop a wireless monitoring system based on ZigBee and CAN bus, which realized the real-time transmission of underground-well data for the pressure monitoring requirements of coal mines. Based on the terminal monitoring device (deployed in the hydraulic prop, integrated pressure sensor, ZigBee module and intrinsically safe power supply to collect pressure data), routing monitoring device (using MCP2515 controller and CTM1050T transceiver to realize protocol conversion)and the ground monitoring center (receiving data through industrial Ethernet and displaying the state of the prop in real time), the architecture design is built. It is suitable for underground support (such as high gas mine)which needs real-time pressure monitoring. This equipment can realize 7 multiplied by 24h real-time monitoring, reduce labor costs by 60%, and transmit data reliability more than 95%.

Table 2 Single hydraulic prop equipment situation table

Time	Author	Research method	Innovation	Effect
2013	Gao Xia et al	AutoCAD Design and Hydraulic Manual Calculation	Pure water is used as the working medium of the hydraulic system.	The pure water pillar is feasible and has an anti-corrosion effect on the coating process.
2014	Li Zhanliang et al	Pro/E, MATLAB and ADAMS co-simulation	Numerical simulation co-simulation	Virtual test cost savings of 30%
2019	Wang Xiujuan et al	Mechanical test and engineering application of plug-in structure	Combined single hydraulic prop	The mass of single hydraulic prop is reduced by 34%, and the height of liquid injection is reduced by 15%.
2011	Wang Weifeng	Practical application analysis of tunneling working face	The use of reinforced composite materials reduces the weight of the pillars and facilitates downhole transportation and installation.	Compared with the traditional support equipment, the installation speed is increased by more than 50 %, and the roadway excavation cycle is shortened.
2019	Gao Xuan	$\mu C/OS-$ Ⅲ and ZigBee systems	Digital twin of ZigBee and CAN hybrid network	Wireless monitoring delay is less than 30 ms, packet loss rate is less than 5 %.

The temporary support of single hydraulic prop is convenient for the recycling of working surface, and it can be completed by manual operation without complex device. However, the quality of support depends on the operation specification of workers. Human error can easily lead to uneven support force, time-consuming and labor-intensive, high risk coefficient, and dependent on the operation of workers.

2.3 Stepping Self-moving Equipment

With the development of roadheader equipment, the speed of roadway excavation is increasing, and the problem of ‘ imbalance between excavation and support ‘ is becoming more and more serious. In order to solve this problem, many scholars in China have developed a step-by-step self-moving temporary support equipment to achieve balanced excavation and support. The situation of self-moving temporary support equipment is shown in Table 3.

In terms of structural optimization, Ma Zhimin(Ma Z M, 2014) developed new temporary support equipment for arched roadways with extremely unstable coal and semi-coal rock roofs, as shown in Figure 5. The main body adopts flexible roof beam system (special buffer design is adopted to avoid secondary roof damage, which can adapt to different roof deformation); self-moving base (equipped with a bottom lifting jack to ensure mobile stability); the intelligent height adjustment mechanism (integrated laying function, which can adapt to 2.8~3.5m different roadway sections) has three parts. Pro/E is introduced into the design of mine support equipment, and the integration of support, self-moving and elevation functions can reduce manual intervention. Using FLAC3 D to establish the surrounding rock model of the roadway, the stress at the top and side of the roadway is the largest, the local stress can reach 9 multiplied by 105Pa, and the maximum deformation can reach 30mm. Design and optimize the structure of four key components.

Design four-link structure : improve the stability and bearing capacity of the support; hydraulic system design: provide strong support and flexible height adjustment; design base design: enhance the overall stability of the bracket; design net laying mechanism and bottom lifting mechanism: adapt to different roadways and improve the operation convenience of support. Finally, the mechanical analysis of the key components (column, bottom hydraulic cylinder, pin shaft) and the grounding specific pressure and longitudinal stability analysis of the base to the bottom plate are carried out to verify the rationality of the support. This equipment is suitable for extremely unstable roof coal rock, half coal rock arch roadway. Using this equipment, the uniformity of the contact pressure distribution of the top beam is increased by 35%, and the secondary damage of the roof is reduced. The self-moving speed of 0.8m/min is three times that of traditional support. In order to verify the effectiveness of the stepping self-moving support, Li Bingbing(Li B B, 2013) took Shendong Bulianta Mine as a practical application case. The bolt suspension and hydraulic drive stepping mechanism is adopted, and the bottom support is cancelled to optimize the suspension support structure. This equipment is suitable for roadways with a height of less than 2.5m. Using this equipment, the optimization of supporting space occupation is reduced by 40%. Yang Donghui(Yang D H et al., 2015) developed a safe, reliable and easy-to-operate new type of step-by-step self-moving advanced temporary support for the problems of untimely support, low strength, high labor intensity and high cost in the traditional temporary support method of tunneling roadway. The structural optimization of the stepping mechanism is carried out by using the integrated design of the frame sliding alternating stepping structure and automatic laying device. This equipment is suitable for high stress roadway. This equipment is used to realize the synchronous operation of excavation and support, the efficiency of laying network is improved by 66.7%, and the displacement time of support is shortened to 5 minutes once. Meng Pengke(Meng P K, 2024) in order to improve the strength and stiffness of the mechanism, to ensure its stability and reliability in the process of operation. The static structure analysis and modal analysis of the arch step self-moving advance support are carried out. The arched top beam and grid rib plate, and the natural frequency are increased to 18.09Hz to optimize the design. This equipment is suitable for deep, high-stress roadways. By using this equipment, the vibration amplitude is reduced by 52%, and the resonance of 8-12Hz operation is effectively avoided.

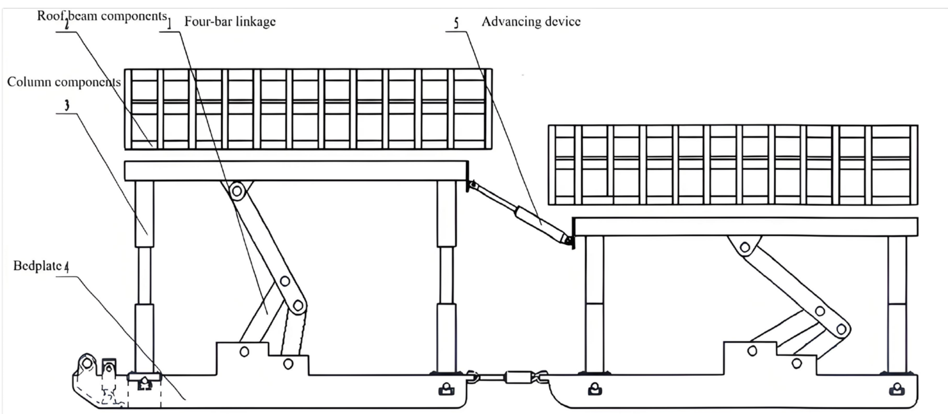

Figure 5 New temporary support equipment diagram(Ma Z M, 2014)

In terms of product research and development, Liu Yizhu(Liu Y Z, 2019) designed a ‘walking, cross-support’ temporary support device for ‘ walking and cross-support ‘ in view of the low efficiency of the ‘ one excavation and one anchor ‘ mode in the tunneling process and the long occupation time of temporary support, as shown in Figure 6. The device is divided into odd and even groups of brackets. The first group has a front probe beam to assist the upper anchor net. The top beam is connected by a ball hinge. The pushing mechanism is a shear mechanism. The length of the two sides is different, so that the front and rear groups have a certain angle to achieve pose adjustment to adapt to the turning conditions. The device is connected by eight single sets of supports through the pushing mechanism, and the whole is straddled above the roadheader. Each single group of brackets is equipped with two column legs, which can adjust the height of the bracket. A pushing mechanism is set between a single group of stents to adjust the distance between each group of stents. The design of the top beam adopts an X-type decentralized independent system for mechanical design. CAN bus electro-hydraulic control system and turning adaptive module (radius more than 6m) is used as the core technology. This equipment is suitable for roadways with turning conditions. The adaptability of this equipment to turning conditions is 100% (traditional equipment is only 50%), and the shift deviation is less than 50mm. Yu Changhong(Yu C H, 2024) designed the stepping self-moving support equipment for the problem of excavation and support balance in coal mine excavation roadway, as shown in Figure 7. The equipment is divided into front-middle-back three frames, and the temporary support is upgraded from passive protection to active stress regulation through electromechanical-hydraulic control as the core. The integrated device of portal hydraulic support, track pushing mechanism, drilling and anchoring mechanism, net laying mechanism, roadway clearing mechanism and side support mechanism is developed as a mechanical structure. The hydraulic system is composed of a control cabinet, frequency converter, emulsion pump station, combined operation valve, control substation, two-way safety valve with safety valve, actuator and pipeline. This equipment is suitable for a high-load supporting roadway under complex geology. This equipment is used to realize continuous support of a 60m long roadway, and the installation time is reduced by 70%. Yu Limin et al(Yu L M et al., 2009) realized the automatic construction of the advanced temporary support in the 2-3m empty roof area at the front end of the tunneling head. The roof anchorage suspension and two-way hydraulic stepping mechanism are used as the core technology. This equipment is suitable for roadways with stable roofs. This equipment is used to realize the support speed of the empty roof area up to 1.2m/min, and the risk of empty roof operation is eliminated.

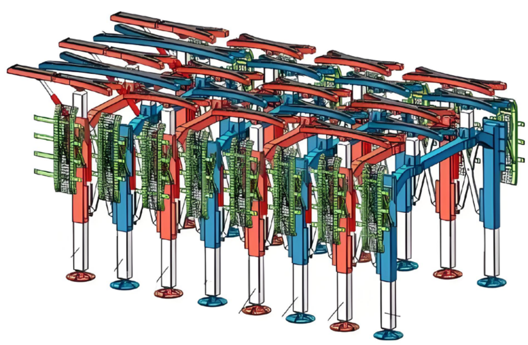

Figure 6　Temporary support equipment diagram of the following machine walking(Liu Y Z, 2019)

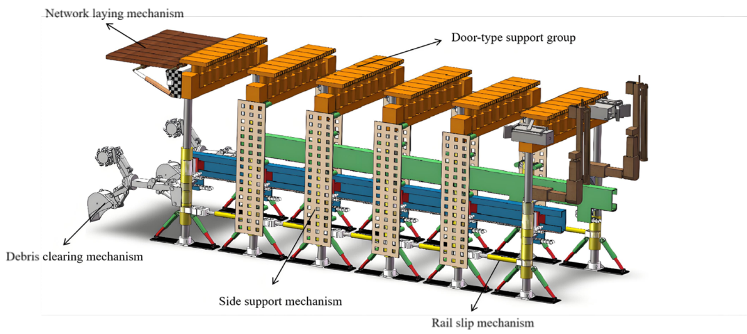

Figure 7　Step self-moving bracket equipment diagram(Yu C H, 2024)

In terms of parameter optimization, Jia Zhijun[28]et al., in order to improve the supporting effect of the comprehensive excavation work. The rigid-flexible coupling model analysis method is used to optimize the damping coefficient. Using this equipment, the vibration acceleration is reduced from 18.0m/s2 to 6.5m/s2 (64% reduction), and the life of the bracket is prolonged by 2.3 times.

Table 3 Self-moving temporary support equipment table

Time	Author	Research method	Innovation	Effect
2013	Ma Zhiming	FLAC3D roadway modeling and Pro/ E virtual prototype verification	Flexible top beam design and self-moving slide rail system	Flexible roof beam reduces roof damage, and the self-moving system simplifies operation.
2013	Li Binbin	Engineering case study	The process flow of ‘ segmented pushing and alternating support ‘ is proposed.	Solved the problem of automatic support
2015	Yang Donghui et al	Frame sliding alternate stepping structure and field test	Integrated design of laying network; stepping multi-stage support	The work efficiency is improved by 66.7%, and the support-netting synchronization is realized.
2024	Meng Pengke	Modal analysis, finite element analysis	The modal analysis is introduced into the research on stepping support.	The natural frequency (18.09 Hz) is much higher than the operating frequency (8.25 ~ 12.32Hz), and there is no risk of resonance.
2019	Liu Yizhu	Elastic-plastic theoretical calculation, Ansys analysis, and CAN bus control	Adapt to turning conditions; integrated CAN bus system	Adaptive turning conditions, coordinated control of excavation and support
2024	Yu Changhong	Ansys analysis and SolidWorks modeling	Odd-even grouping support, hydraulic proportional valve control optimization	Realize the balance of excavation and support, shorten the operation cycle by 30%.
2009	Yu Limin et al	Theoretical design and hydraulic drive	Design of a bolt suspension three-claw stepping mechanism	The bolt suspension and stepping mechanism realize rapid support in the empty roof area and support parallel operation.
2022	Jia Zhijun et al	dynamic simulation	The rigid-flexible coupling damping structure is introduced into the temporary support equipment.	The damping structure reduces the peak acceleration under the beam by 64% (18.0-6.5m/s2), and the vibration absorption effect is remarkable.

The advantage of the self-moving temporary support is that it can improve the automation level with the movement of the roadheader, but the disadvantages are also obvious, such as the phenomenon of ‘pressure rubbing’ of some equipment and the repeated support of the roof, resulting in roof damage.

2.4 Airborne Equipment

Airborne temporary support equipment usually refers to the support system installed on the roadheader or other tunneling equipment, which can provide support immediately during the tunneling process to prevent the collapse of the roadway. However, the installation of temporary support devices will more or less affect the performance of the roadheader. In order to minimize the impact of the performance of the roadheader, there are usually two kinds of long track sliding configuration and direct hinged configuration. The airborne temporary support equipment is shown in Table 4.

In terms of device development and application, Jian Bo(Jian B, 2007) studied the working principle and structural characteristics of the hydraulic system of the roadheader ‘s airborne hydraulic temporary support, and pointed out that this technology can significantly improve the support speed and safety. Li Junfeng and Liu Bin(Li J F & Liu B, 2010) developed a new type of airborne hydraulic temporary support machine. The test proved that it improved the driving speed and reduced the labor intensity of workers. Liu Jing and Feng Juan(Liu J & Feng J, 2012) designed the airborne temporary support device of the fully mechanized excavator for the problem of slow temporary support of the front exploration beam. The application in Jisan Coal Mine shows that it can effectively control the roof deformation.

In terms of improving efficiency and safety, Wang Shuai(Wang S, 2014) proposed an airborne temporary support scheme based on the structural characteristics of the cantilever roadheader, aiming to improve the support efficiency and safety. Guo Fenchao and Chang Bofeng(Guo F C & Chang B F, 2020) Through the application of ZLJ-20 airborne temporary support device, its effectiveness and automation advantages in Hongliulin Coal Mine are verified, and the integration of excavation and anchoring and the simplification of process are realized.

In terms of intelligence, Ma Changqing(Ma C Q et al., 2024) and other researchers represented the latest technical direction. They designed an adaptive airborne temporary support and used SolidWorks modeling and AMESim simulation analysis to verify that the support device can dynamically adjust the support force according to roof changes.

Table 4 Airborne temporary support equipment situation table

Time	Author	Research method	Innovation	Effect
2007	Jian Bo	Design and simulation analysis of adaptive airborne temporary support	A modular structure design is proposed to integrate the support device with the body of the roadheader.	Airborne hydraulic support improves support speed and safety.
2010	Li Junfeng and Li Bing	Improve the traditional front beam support	The adjustable support height design is introduced to adapt to different roadway sections.	The new support machine improves the tunneling speed and reduces the labor intensity.
2012	Liu Jing and Feng Juan	Replacing the traditional front beam support	The folding multi-stage support arm realizes the dynamic expansion of the support area through the hinged structure.	The device significantly reduces roof subsidence and improves support efficiency.
2014	Wang Shuai	Support design combined with the characteristics of the cantilever roadheader	Double hydraulic cylinder synchronous control technology to avoid supporting roof tilt	Improve support efficiency and safety, alleviate the contradiction between excavation and support.
2020	Guo Fenchao and Chang Bofeng	Field application: verify the applicability of the airborne support device in a coal mine	The pressure sensor feedback system is introduced to monitor the roof pressure in real time and adjust the support force.	Realize the integration of excavation and anchoring, and improve the level of safety and automation
2024	Ma Changqing et al	SolidWorks modeling and AMESim simulation analysis	Adaptive support system of joint simulation	The supporting force can be dynamically adjusted to adapt to different roof inclinations.

The core advantage of airborne temporary support is its mobility convenience and ability to keep up with the head, which greatly improves the safety of operation and a certain degree of production efficiency. However, its disadvantages are mainly reflected in high cost, adaptability limitation to geological and roadway conditions, relatively limited support strength, and dependence on host performance and space.

3 The Main Problems Existing in the Temporary Support of Fully Mechanized Roadway

Although the temporary support technology and equipment have made significant progress, there are still many challenges in practical application and sustainable development, which restrict the further improvement of tunneling efficiency and the fundamental guarantee of operation safety. The main problem is shown in Figure 8.

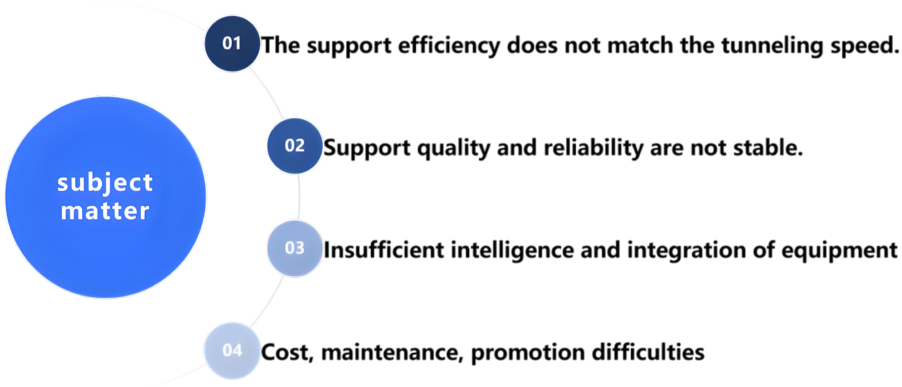

Figure 8 The main existing problems of temporary support in fully mechanized roadway

(1) Support Efficiency and Tunneling Speed do not Match

The temporary support of the front beam and the single hydraulic prop still relies heavily on manual operations such as handling, installation, disassembly, etc. The process is cumbersome and the cycle time is long, which has become a ‘ necking ‘ problem that restricts the operation of ‘ excavation and support balance ‘. Even the level of automation and intelligence of step-by-step self-moving and airborne temporary support equipment still needs to be improved. Some equipment moving and supporting actions still need manual intervention or monitoring, and the fluency of collaborative operation is insufficient. The preparation links such as equipment positioning, condition inspection and system start-up take a long time, which affects the overall operation rhythm.

(2) Unstable Support Quality and Reliability

The support quality (setting force, working resistance) of single hydraulic prop and other equipment is highly dependent on the standardization of manual operation, and human error will lead to insufficient support force. In the process of moving the self-moving equipment, there is a common phenomenon of ‘ rubbing the roof with pressure ‘ or repeated support, which is easy to disturb the broken or weak roof, cause secondary damage or even local caving, and increase the difficulty and safety risk of permanent support in the later stage. Failures such as sealing failure of the hydraulic system and fatigue of the mechanical structure often occur, which affect the continuous and stable operation of the hydraulic system and the reliability of support.

(3) Insufficient Intelligence and Integration of Equipment

The real-time accuracy and perception ability of key information such as equipment attitude and support force distribution of most equipment are insufficient. The monitoring ability of some existing equipment is mostly single-point and local, and the lack of overall fusion monitoring fails to achieve the true sense of intelligence. The level of collaborative operation between temporary support equipment and roadheader, bolt drilling truck, transportation system and other equipment is low. It is difficult to achieve real integrated and efficient operation due to the lack of a unified ‘ digging-supporting-transportation-communication ‘ information interaction platform and collaborative control mechanism.

(4) Cost, Maintenance, Promotion Difficulties

For small and medium-sized coal mines, advanced stepping self-moving, robot systems and other equipment are expensive and difficult to promote. The maintenance of mechanical-electrical-hydraulic integrated equipment has high technical requirements and high cost, and the harsh underground maintenance environment affects the equipment operation rate. Intelligent equipment has a high level of skill knowledge for operation and maintenance personnel, and the training cost is increased.

4 Outlook

According to the Shanxi Province Emergency Management Department's" on the strengthening of coal mining continuous tension control work of several measures" interpretation, in China's coal production, the majority of the scale of the excavation roadway is huge. However, the phenomenon of ' heavy coal mining, light excavation ' has existed for a long time, and the problem of mining imbalance has become more and more prominent. The complex temporary support process and the slow support speed have become an important factor restricting the rapid excavation of coal roadway. For the occurrence of this phenomenon, the emergence of safe, efficient and intelligent support equipment has become particularly important.

For the above requirements and the implementation of the policy of " equal emphasis on mining and tunneling first, " the development of a coal roadway tunneling robot system has become a rigid demand, which can solve the problem of " fast excavation and slow support. "Chinese scholar Ma Hongwei(Ma H et al., 2020; Ma H W et al., 2023; Ma H W et al., 2024) and his team have made many contributions to the integration of 'excavation', 'branch', 'transportation' and 'communication' in the robot system. Firstly, in 2020, an intelligent tunneling robot system integrating load cutting, temporary support, drilling anchor and anchor net transportation was proposed to realize multi-process parallel coordination. In 2023, the shield temporary support device for coal roadway excavation was proposed, and the problems of large construction weight difficult transportation and disassembly were solved. In 2024, the hydraulic control system of a temporary support robot driving under pressure was studied. When driving under pressure, the support hydraulic system and the driving hydraulic system work at the same time. While ensuring that the temporary support robot's decompression does not leave the top, it is under pressure and moves forward steadily with the roof at all times.

In order to cope with the current challenges, the temporary support equipment of fully mechanized excavation roadway needs to be developed in a safe, efficient, intelligent and green direction. The development trend of temporary support equipment should be shown in Figure 9. ① Highly automated and unmanned: The equipment should be unmanned from the whole process of automatic positioning, rapid positioning, autonomous movement, precise positioning, adaptive adjustment to the automatic moving frame, and gradually realize unmanned, greatly improve the support efficiency and ensure the safety of personnel. ② Intelligent and adaptive support: A real-time dynamic monitoring system for surrounding rock-support interaction is constructed by integrating various high-precision sensors such as pressure, displacement, dip angle and acoustic emission. Based on AI algorithms such as deep learning, a surrounding rock-support interaction model is established to realize real-time dynamic control of support Parameters. ③ Integrated operation: based on 5G communication and an intelligent management and control platform, the integrated operation of supporting equipment, roadheader, bolt drilling rig and transportation equipment is realized, and the real parallel operation of excavation and support is realized. Develop a multi-modular concept to integrate various functional modules such as mesh laying, support, dust removal, and transportation. ④ Green environmental protection: promote the application of environmentally friendly working media in hydraulic systems to reduce emulsion pollution; improve the wear resistance and corrosion resistance of key components, optimize the structure to facilitate the replacement of components and prolong the service life of equipment.

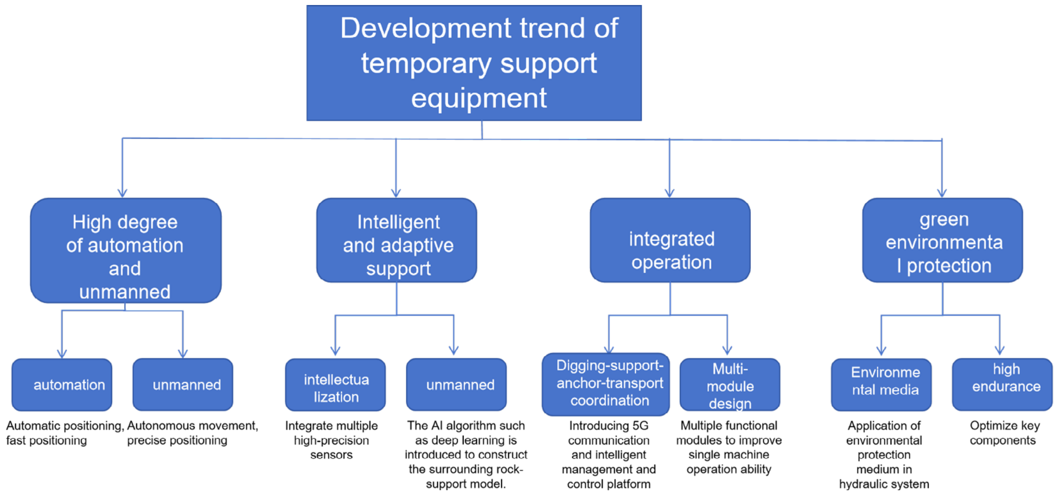

Figure 9 Development trend of temporary support equipment

5 Conclusion

The safe and efficient tunneling of coal mine roadway is the core guarantee to realize the sustainable development of coal resources. This paper systematically examines the evolution of the temporary support technology of fully mechanized excavation roadway from the traditional support period, the mechanized support period, to the intelligent support period, and reveals the internal relationship between the technical upgrading and the improvement of the excavation efficiency. At present, temporary support equipment still faces perception accuracy issues.

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