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Research and Field Application of a Down-Dip Withdrawal Method for Heavy Fully Mechanized Hydraulic Supports in a Steeply Inclined Longwall Face

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Abstract

The down-dip withdrawal of heavy hydraulic supports under a large face inclination remains a bottleneck affecting the safety and efficiency of longwall face relocation. In this study, a down-dip withdrawal technology for heavy fully mechanized hydraulic supports was developed and field-tested at the 2091 working face of No. 6 Coal Mine, Hebi Coal Company. The coal-pillar layout during the closing stage was optimized to improve the coal recovery ratio and reduce resource losses. The pre-withdrawal support scheme, including a flexible-mesh artificial roof, was redesigned to enhance roof stability during the withdrawal period. The withdrawal process was also optimized to enable parallel operations of support alignment, loading and disassembly. Mechanized withdrawal equipment was introduced to address the anti-overturning and anti-sliding requirements during top-to-bottom transportation of fully mechanized supports, thereby realizing safe and mechanized support withdrawal. Field application showed that the face relocation time was reduced by 55%, while labor intensity, production cost and the risk of spontaneous combustion were substantially decreased.

Keywords

Retrieval of heavy supports in coal mines; Technology; Reasonable optimization

1. Introduction

Rapid withdrawal of a fully mechanized working face is not only a key task in coal-mine safety management but also an essential link in safe and efficient coal production. In recent years, the withdrawal of steeply inclined working faces has involved several technical challenges, including roof control, support dismantling and inclined-roadway transportation; these challenges directly affect the safety and schedule of face withdrawal[1]. With the development of fully mechanized mining and the upgrading of coal-mining equipment, the size and weight of equipment have increased, which has further increased the difficulty of safe withdrawal from fully mechanized working faces. First, the existing mines in the Hebi mining area were mostly constructed in the late 1950s and adopted vertical-shaft, multi-level uphill and downhill development. After nearly 60 years of production, the mining depth has exceeded 700 m, and the active mining horizons are the third or fourth levels, resulting in numerous transportation links and low transport efficiency. Second, as the size and weight of mining and excavation equipment have increased, and because of the limited hoisting capacity of the auxiliary shaft, all equipment must be dismantled before being transported underground, which increases the number of mine cars required. Third, strata-pressure behavior in deep roadways is highly pronounced; roadway deterioration is common, and transportation conditions are poor. Fourth, the underground geological conditions are highly complex, the withdrawal conditions are unfavorable, work efficiency is low and safety risks are high. The 2091 working face investigated in this study has an inclined length of 110 m and an average gradient of 15 deg. It contains 73 ZF6400/19/32D hydraulic supports, each with a net weight of 25 t. After disassembly, each support requires four cars for transport, resulting in a large transport workload and significant hoisting-related safety risks.

In some working faces, the conventional bottom-to-top, support-by-support withdrawal process is not suitable. Examples include faces with long support-withdrawal routes, large roadway-rehabilitation workloads and long preparation periods. Under such conditions, delayed closure of a stopped working face may increase the risk of spontaneous combustion in residual coal near the stopping line. Research on the down-dip withdrawal of heavy hydraulic supports under a large inclination provides technical support for top-to-bottom support removal in fully mechanized working faces, offering additional process options and enabling safe face withdrawal. After demonstration and analysis, the 2091 working face was selected as a field test site for developing and applying this technology.

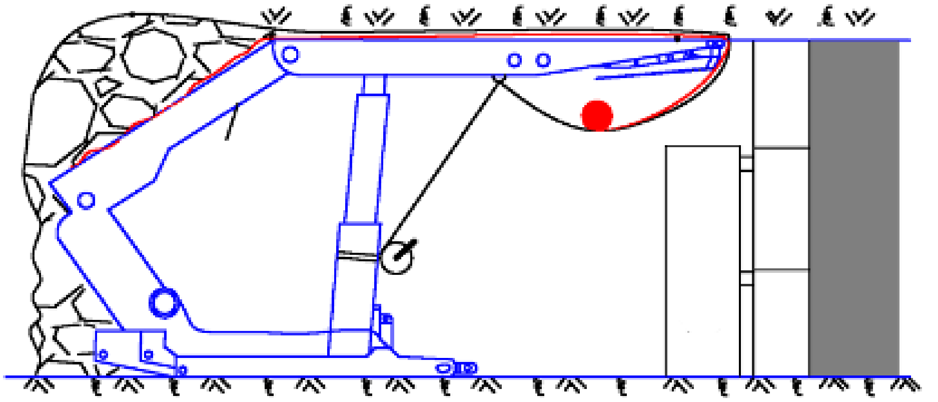
2. Design and Optimization of False Roof Before Fully-Mechanized Working Face Retraction

2.1. Construction Technology of False Roof Before Fully-Mechanized Working Face Retraction

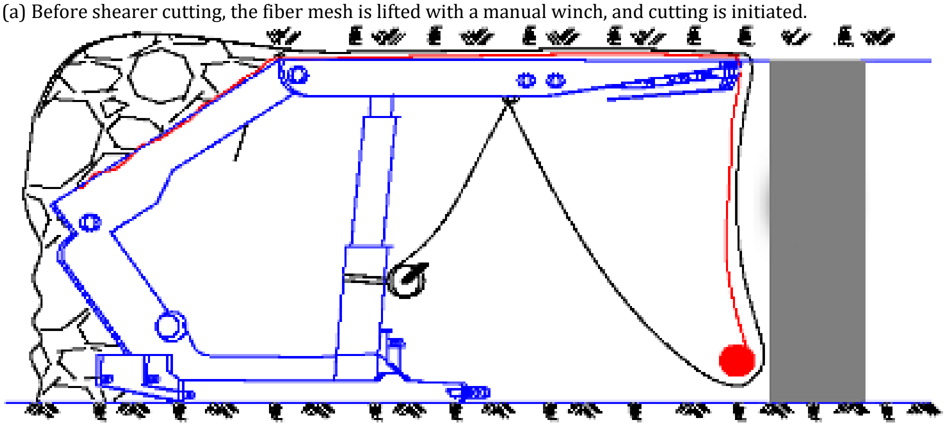
A new terminal-mining process was tested at the 2091 working face. A high-strength polyester-fiber flexible mesh with high strength, good integrity and small, uniform openings (single sheet: 16 m wide and 45 m long) was used to replace the traditional metal mesh and plastic strap mesh. This significantly improved the roof-protection effect and enhanced the flatness of the roof in the terminal-mining area, thereby creating favorable conditions for safe support withdrawal. The process reduced manual mesh transportation, mesh laying and frequent mesh connection in front of the supports, greatly improving work efficiency and shortening the construction period by 6 days. The terminal-mining distance was reduced from 17 m to 14 m, which increased the coal-recovery distance by 3 m and improved the recovery ratio during the final mining stage. The operation is simple: the mesh sheet is lifted and suspended integrally in one step, enabling a mechanized cycle of mesh lowering, support advance and mesh lifting after coal cutting. This approach eliminates frequent manual mesh connection in front of the supports and overcomes the poor laying and connection quality associated with manual metal-mesh installation, thus considerably improving the safety factor.

2.2. Construction Technology of Flexible Mesh 2 Anti-toppling and Anti-sliding Technology for Downward Support Retraction

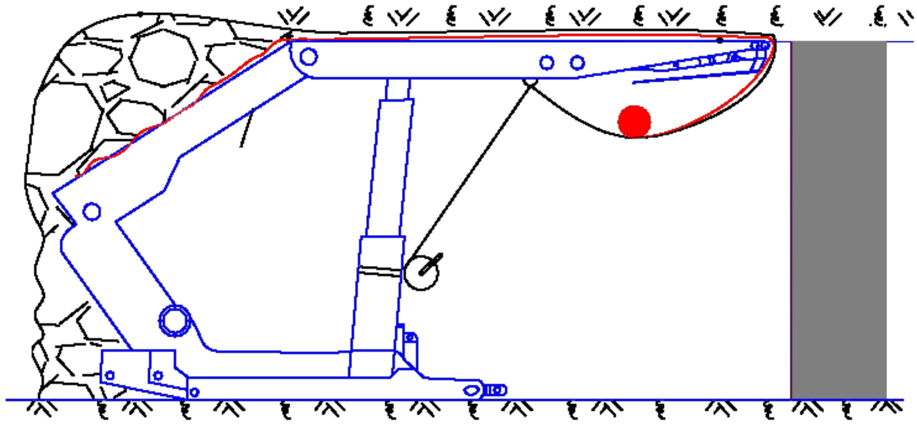
The main steps for mesh installation at the working face are shown in Fig. 1.



(a) Before shearer cutting, the fiber mesh is lifted with a manual winch, and cutting is initiated.



(b) After shearer cutting, the manual winch is released to lower the fiber mesh, followed by support advance.



(c) After support advance, the fiber mesh is lifted with the manual winch, and the shearer returns to clear loose coal.

Figure 1. Principal steps of mesh installation at the working face.

(1) After mesh installation, the shearer performs normal coal cutting. Personnel operate the winch to lower the mesh 5-10 supports behind the rear drum of the shearer, while support operators advance the supports 2-3 supports behind the mesh-lowering point. In the normal section of the working face, the lowering height of the mesh roll is controlled at approximately 2 m. Before support advance, the mesh must be lowered into position and the front canopy must be lowered by approximately 200 mm; otherwise, the operation is prohibited to avoid damaging the mesh sheet or the steel rope used for mesh lifting[2].

(2) After support advance, the winch is operated 5-7 supports behind the support-advance point to lift the mesh. At least five workers should operate the winch simultaneously. The mesh is lifted, and the procedures of coal cutting, mesh lowering, support lowering, support advancing, mesh lifting and coal cutting are repeated until the working face reaches the stopping position.

(3) The overlap length between two mesh rolls must not be less than 3 m. The overlapped section is tied with iron wire in a uniformly distributed three-staggered pattern to ensure sufficient lap strength. During shearer cutting and support advance, because one end of the mesh roll lacks pulling force, the two mesh sheets should be tensioned against each other in advance using a chain block. This prevents the overlap length from gradually decreasing as the sheets are pulled toward the two sides, thereby avoiding failure to maintain a proper overlap[3].

(4) After the working face advances to the support-stopping position, the construction process and requirements are the same as those used for metal-mesh installation.

3. Anti-toppling and Anti-sliding Technology for Downward Support Retraction

3.1. Sequential Dismantling of Supports from Top to Bottom

(1) The uppermost transition support, No. 73, is withdrawn first. In front of Support

No. 73, a pair of dip-parallel lifting-beam support sets is installed 200 mm from the forepoling beam and tightened with wooden wedges. When the support is lowered, the rear beam and side guard plates are fully retracted, and all connecting devices and pipelines on the support are removed last[4].

(2) Before lowering the support, the hook of No. 3 winch is attached through a guide pulley to the upper-side main leg of the support so that the wire rope remains tensioned. The winch is then started to adjust the support and prevent side overturning during pulling and transportation, until the support is adjusted to a normal transport state.

(3) As supports are removed and the shielding supports and dip-parallel lifting-beam support sets are moved, three timber point props are installed beneath each of the two I-steel beams on the original support at the rear (upper) end of the lifting-beam set before beam shifting. These props retain the roadway as a return-air passage during the withdrawal period.

(4) During support recovery, the No. 1 winch rope is fastened to the upper end of the front lower prop of the support, and a fixed guide pulley is connected to the No. 1 winch rope. The No. 1 winch is started to pull the support to a position 200 mm from the coal-wall props. The guide pulley is then removed, and the No. 3 winch rope is connected to the rear-beam jack. The No. 1 winch rope is subsequently connected to the support base box, and the No. 1 winch is restarted to adjust the support into the support-removal passage.

(5) During support haulage, the No. 3 retaining winch and No. 1 winch must be started intermittently and coordinated properly. Accelerated downward sliding of the support during haulage is strictly prohibited. Before the No. 1 winch is started, all components and connections of the side guard plates must be carefully inspected and confirmed to be secure. The support is pulled to the turning point between the working face and the lower gate road and is then pulled by the No. 4 winch in the lower gate road to the loading position.

3.2. Working Principle and Main Structure of TYH300 Shift Adjustment Device

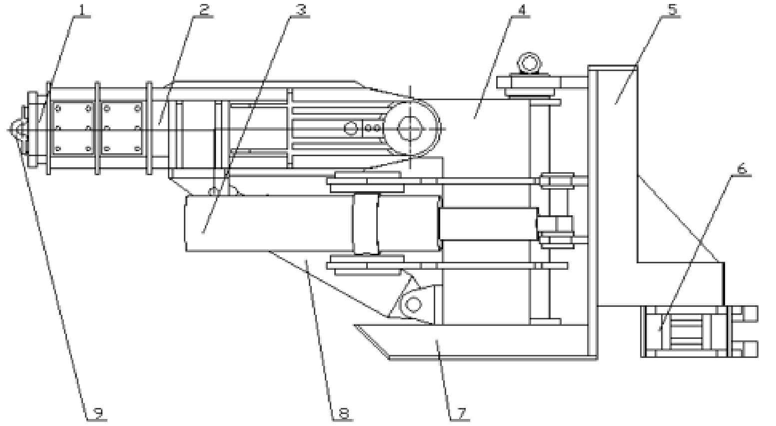
The base 5 is first fixed to the cross beam 7. The rotary cylinder 3 drives the swing seat 4 to rotate toward one side of the equipment to be pulled. The hoisting ring 9 is connected to the equipment, and the lifting cylinder (8) raises the hoisting ring mounted on the outer arm 2 and inner arm 1, thereby lifting the equipment. The rotary cylinder 3 then rotates the swing seat 4 in the opposite direction, transferring force to the outer arm 2 and inner arm 1 and driving the hoisting ring 9 and the equipment to move together. After the equipment reaches the required position, the rotary cylinder 3 is stopped. The stretching cylinder on the outer arm 2 extends the inner arm 1, and the equipment is laterally shifted by means of the hoisting ring 9 and chain. The equipment is then pulled out and transported using a winch, as shown in Fig. 2.

3.3. Retraction Construction Technology

(1) Preparations before support withdrawal

When the working face is 12 m from the stopping line, the first wire rope is installed. When the face is 10 m from the stopping line, two Phi 15.5 mm steel wire ropes are installed for every 1.8 m of advance, with a rope spacing of 900 mm; 13 ropes are installed in total.

During cutting of the penultimate web of coal, the supports are not advanced. Instead, all front canopies are fully extended and set against the coal wall. After the shearer returns, the conveyor pan is pushed toward the coal wall. During cutting of the final web of coal, two 2 m Korean pine round timbers are installed above each support and extended to the coal wall as each support position is cut; the shearer is stopped at the upper head. When the timbers are installed, one support position must be cut and timbered at a time. Where an unsupported roof or rib spalling occurs, a one-beam two-prop timber support must be installed, and rib-side props must be set. During timber installation, the face conveyor must be powered off and locked out. During recovery of the last web of coal, the edge of the diamond mesh must hang down to the floor. During the final two webs of coal, the Pi-shaped beams are not shifted. Where the support cannot reach the coal wall, DZ-2.5 single hydraulic props and Phi 18 cm x 2 m timbers are used to support the roof, ensuring a one-beam two-prop support configuration. After the final web is cut, wooden bolts (Phi 35-40 mm, 2.0 m long) are installed in the coal wall to prevent rib spalling and coal flow[5].



1, inner arm; 2, outer arm; 3, cylinder; 4, swing seat; 5, base; 6, hydraulic travelling device; 7, cross beam; 8, cylinder; 9, hoisting ring.

Figure 2. Schematic of the hydraulic support adjustment and transfer device (support-withdrawal manipulator).

(2) Requirements for the support-removal passage

According to the actual dimensions of the hydraulic supports, the support-removal space in the working face must provide a clear width of not less than 4.2 m (the clear distance between the support base feet and the coal wall) and a clear height of not less than 2.8 m (the distance between the top of the front canopy and the coal-seam floor).

(3) Support withdrawal process

During withdrawal of the 2091 fully mechanized caving face, the three transition-support groups at the lower end of the face (Supports No. 1-3) are withdrawn first. Hydraulic single props are then combined with winches to adjust the shielding supports in the sequence of No. 6, No. 5 and No. 4. Supports No. 4, No. 5 and No. 6 serve as shielding supports, and support removal begins from Support No. 7, so that the shielding supports are adjusted to the optimal state for withdrawal. Subsequently, the dismantled main body and cross beam of the TYH-300 hydraulic support adjustment and transfer device are transported to the open-off cut entrance, placed on skids, dragged in front of the shielding supports and reliably connected. The support extraction device consists of a pushing cross beam, a frame and a swing arm. Two rotary jacks and two lifting jacks are arranged between the frame and the swing arm. Hydraulic pipelines and operating valves are assembled and installed according to the instruction manual. The operating valve is placed in a safe position below the shielding supports, and the pump-station pressure is adjusted to 20-31.5 MPa. After installation, the hydraulic support adjustment and transfer device (manipulator) is commissioned.

After the mechanical connections and hydraulic pipeline connections are checked and confirmed to be normal, hydraulic fluid is supplied. When all jacks operate flexibly, the manipulator is used for support extraction, as shown in Fig. 3. The operation steps are as follows.

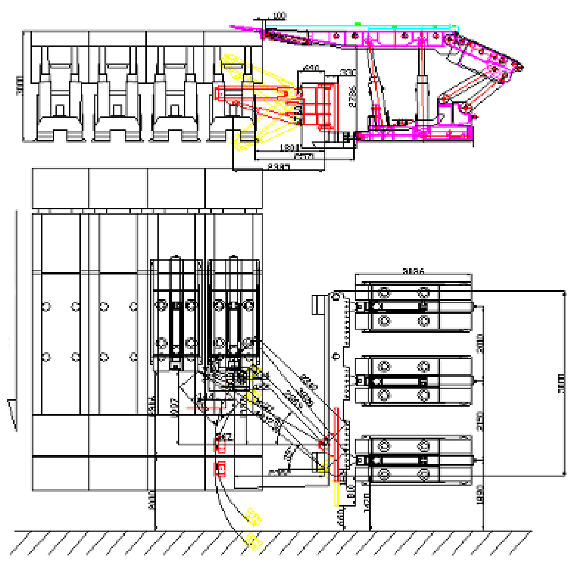


Figure 3. Schematic diagram of support extraction and alignment using the hydraulic support adjustment and transfer device (manipulator).

The manipulator is swung to the position of the support to be withdrawn. A Phi 34 chain ring and connecting ring are used to reliably connect the front end of the swing arm to the front end of the base box of the support being extracted. The lifting jacks and rotary jacks of the extraction device are operated to slowly pull the support forward by 2.8 m. After the rear end of the base box has been extracted and the front canopy is 0.5 m from the coal wall, the telescopic jack of the swing arm is operated to swing the front end of the extracted support toward the tailgate side by 7 deg, thereby aligning the support. The operating valve is then stopped, the connecting chain is loosened and the rigging is removed. After confirmation, the telescopic arm is retracted, and a face-end prop-recovery machine is used to drag the support onto the skid. The steps of pushing, moving and pulling the shielding supports are repeated until the shielding supports reach the designated position. The roof is maintained, and coal fines in front of the extraction device are removed promptly to prepare for the next extraction cycle. The extracted support is pulled by the winch at the upper safety exit to the loading platform at the upper safety exit. The loaded support is then hoisted to the support assembly station in the upper gate road for dismantling and outward transportation. After all supports are withdrawn, the manipulator is dismantled and hoisted to the surface.

(4) Application effect of rapid-withdrawal equipment

At the 2091 fully mechanized caving face, approximately 2 h were required for each support to be withdrawn from the stope, loaded, transported to the assembly station and dismantled. Three to four groups of supports could be withdrawn per shift, whereas the traditional method allowed withdrawal of at most two supports per shift. Thus, the work efficiency was approximately doubled. With the new process, the average support-withdrawal time was shortened by 55%. Because the prop-recovery winch was no longer used, the risk of injury caused by rope breakage was eliminated, and frequent relocation of the prop-recovery machine was avoided, thereby improving safety. After the manipulator was connected to the support to be withdrawn, it could complete support extraction and alignment in a single operation. The entire process required only 8 min, saving more than 30 min compared with the traditional method. The withdrawal efficiency of the working face was greatly improved, providing a time guarantee for the prevention and control of spontaneous combustion, saving substantial investment and reducing the cost of fire-prevention and extinguishing materials by approximately RMB 700,000, thus ensuring safe mine production.

4. Conclusion

The down-dip withdrawal technology for heavy hydraulic supports under a large inclination was studied and applied at the 2091 working face. The terminal-mining process of the fully mechanized caving face was optimized, the mesh-installation length during terminal mining was shortened, recoverable reserves were increased, the service life of the working face was extended, the recovery ratio was improved and resource waste was reduced. A high-strength polyester-fiber flexible mesh was used to construct the artificial roof, and mechanical winches were adopted to assist mesh laying, thereby improving work efficiency. The workload for roadway enlargement and rehabilitation and the preparation time for withdrawal were reduced. Support loading and movement were accelerated, the face-withdrawal time was shortened, and work efficiency was significantly improved. Timely closure of the working face was ensured, and the risk of spontaneous combustion was reduced.

According to specific working-face conditions, the down-dip withdrawal technology for heavy supports under a large inclination can be used to optimize the support-withdrawal process. A support-dismantling platform and hydraulic crane can be adopted for support disassembly, enabling parallel operations of support alignment, loading and dismantling and reducing both engineering workload and labor input. The hydraulic support adjustment and transfer device (manipulator) can extract and align supports in a single operation. The dispatching winch, support-loading traction system and loading platform - a metal trapezoidal body with a 30 deg inclined side to facilitate support climbing and a right-angle side with grooves to fix the flatcar - solve the problems of anti-overturning, anti-sliding and subsidence during top-to-bottom transportation of fully mechanized supports.

The down-dip withdrawal technology for heavy supports under a large inclination not only ensures the safety of hydraulic support withdrawal but also reduces labor intensity and guarantees efficient working-face withdrawal. It yields significant safety and economic benefits and has high potential for wider application.

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