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Design and Traction Power Calculation of Non-interval Drag Pipe Nitrogen Injection for Fire Control

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Abstract

Aiming at the problems of traditional buried tube nitrogen injection that the nitrogen injection spot with intervals in the space causes the failure of continuous nitrogen distribution in goaf, leading to poor inert effect, in addition, the un-recycling of the nitrogen injection pipe causes much resource waste. The nitrogen injection pipe material is always brittle, of which shear performance is better than its tensile performance. Based on this principle, new fire nitrogen injection process (rotating traction and non-interval) is designed, fundamentally solving major defects of buried tube nitrogen injection, which can realize the synchronous movement between nitrogen injection point and the workface. According to the unloading arch principle and the dynamic calculation of trenchless pipe directional crossing technology, the traction power of non-interval drag pipe nitrogen injection for fire control can be calculated and analyzed. By using a geotechnical engineering numerical simulation software, the stress distribution is simulated for the nitrogen injection pipe in the goaf of YAN ZI SHAN mine, and the traction power is calculated based on it, which lays foundation on successful fulfilsments of non-interval nitrogen injection for fire control.

Keywords: nitrogen injection for fire control; rotating traction; trenchless pipe; unloading arch principle; traction power calculation

Nitrogen injection is one of the main methods to prevent gob coal spontaneous combustion and inert the fire zone. At present, buried tube nitrogen injection is common. Its major defects are as follows: (1) Intervals of nitrogen injection points in the space lead to discontinuous division of the nitrogen in goaf. The inert effect is poor and the quantity is large. (2) Alternately discarded nitrogen injection pipe consumes a large amount of materials. The input costs a lot. These two major defects of the traditional buried tube nitrogen injection way are fundamentally solved by non-interval drag pipe nitrogen injection for fire control. On the one hand, it can maintain the continuity of the nitrogen injection points in the space, realizing the continuity distribution of nitrogen in goaf and achieving better inert effect. On the

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other hand, the recycling of the nitrogen injection pipe effectively reduces the waste of materials, which have great economic and social benefits. In addition, according to unloading arch soil pressure calculation method and the related principles of trenchless pipeline directional crossing technology, the traction dynamic calculation is analyzed which lays foundation on the successful fulfillment of non-interval nitrogen injection for fire control [1].

1. Research of non-interval drag pipe nitrogen injection for fire control

1.1. Process of buried pipe nitrogen injection
At present, buried tube nitrogen injection is common. There are two ways to lay out the pipes: (1) Bury a pipe in the goaf along air intake side of workface. Begin injecting nitrogen after the first pipe is buried into the goaf for a certain length, meanwhile, bury the second pipe. Inject nitrogen by the second pipe when it is buried into the border region between oxidation zone and cooling zone in goaf. Then stop nitrogen injection with the first one, and rebury new pipes. Do the cycle until actual mining of work face is finished. This method needs to rebury a new pipe every certain distance (the width of oxidation zone). It is essential to invest plenty of labor and resource to make, load, transport and install the pipes, even worse, the pipes can’t be recycled, which causes a great waste. The position of nitrogen injection point unavoidably jumps in goaf because of the alternative usage of nitrogen injection pipes. So nitrogen spreads discontinuously in goaf, which reduces the inert effect and increases nitrogen amount. (2) Bury the main injection pipes along laneways which are in the next to the intake airways and in the same direction of them. In order to control the injection amount, we need to put gate valves on the sub-pipes which elicit from the main pipes every certain distance. There are several nitrogen release vents every certain distance on the pipes in goaf. They are 20-30cm higher than the coal floor, protected by stone or wood from the occasional blockage of the vents. This method needs a special laneway, so narrow application scope and weak flexibility are the most major defects. Moreover, the sub-pipes make pipe route too complex to be applied widely [2].

1.2. Design principles of non-interval drag pipe nitrogen injection for fire control
In order to overcome the critical defects of traditional buried tube nitrogen injection, the process of non-interval drag pipe nitrogen injection for fire control needs to possess two features as follows: (1) Keep the injection points continuous in goaf to exert the best inert effect; (2) Recycle the pipes to save resource. The pipes are made of high-strength, high-hardness, and well friction-proof brittle material (cast iron and high-carbon steel). The result of tensile and torsion destructive experiment shows: (1) The pipe will break down along with some cross section near the middle point in the tensile destructive test process as shown in Fig.1(a). (2) The pipe will break down along with some helicoids section with 45°angle in the torsion destructive test process as shown in Fig.1(b).

Fig. 1 (a) pipe tensile destructive Test; (b) pipe torsion destructive test
According to related theories on material mechanics, stress condition has nothing to do with the material of the test piece. The fracture cross sections in tensile destructive test and torsion destructive test process are both the section of maximum tensile stress, so all the breaks of pipes are caused by tensile stress, which shows that the pipes shear performance is better than its tensile performance \[3\].

Based on the above described, the process of non-interval drag pipe nitrogen injection for fire control is designed in the way of rotation traction, using nitrogen injection pipe shear performance to overcome the most resistance in the traction process, at the same time, it has the role of loosing the surrounding rock of nitrogen injection pipeline and reducing resistance. And it can keep the synchronous movement between nitrogen injection point and workface to keep the nitrogen injection point continuous in goaf.

2. Overall design of non-interval drag pipe nitrogen injection for fire control

Based on the design principle of non-interval drag pipe nitrogen injection for fire control, the way of rotation and traction is studied and designed which mainly consists of nitrogen injection pipe, wire rope, reduction motor, drawtube, nitrogen injection hole and fixed device.

The device installation of non-interval drag pipe nitrogen injection for fire control mainly includes five parts: (1) Connect the top of nitrogen injection pipe with the dual axle of reduction motor by the chuck. (2) Connect the external entrance of nitrogen with the other end of dual axle of reduction motor by the drawtube, and use link set to fix. (3) The wire rope through the nitrogen injection pipe to test whether it fractures. (4) Make the end of the nitrogen injection pipe thorough into the goaf. The nitrogen injection hole at the end side can ensure the unobstructed nitrogen export when the end of nitrogen injection pipeline jams. (5) Fix reduction motor on the base of end bracket with the fixed device.

There are three steps to implement process of non-interval drag pipe nitrogen injection for fire control: (1) When shearer cuts coal totally, put down the end bracket and start reduction motor to drive nitrogen injection line rotating slowly in goaf. (2) Remove end bracket and draw nitrogen injection pipe out by moving support force of jack on shearer to keep synchronous movement with workface, meanwhile the drawtube automatically systolic. (3) At last, release the drawtube to recover the original state.

3. Traction power calculation of non-interval drag pipe nitrogen injection for fire control

Pipe directional crossing technology is a branch of trenchless technology. Its basic principle is that using horizontal directional drilling to drill a small-bore pilot hole along the track of underground laid predetermined, then using reamer to enlarge the grading hole according to design curve. When the hole meets the requirements, lay underground pipeline. After the borehole work, directional crossing pipe is welded, nondestructively tested and added pressure on. When these requirements are satisfied, pipe joint is welded on the end of pipe. At last, connect reamer, centralizer, rotary joints, custody head and the posterior pipe by drill pipe end of drill and drive drill to pull directional crossing pipe into borehole, and drag out from the other end \[4\].

Compare stress condition of injection nitrogen in the goaf and pipeline in directional crossing, they have the similarities as follows: (1) As the main force subject, both injection nitrogen pipe and traversal pipeline have the same geometrical appearance shape. (2) In the process of traction, the main resistance is from rock-soil around the pipe. Therefore, the traction power calculation of non-interval drag pipe nitrogen injection for fire control could refer to the pull strength formula of pipeline used in directional crossing technology of trenchless engineering \[6-8\].

Pull strength formula is based on the unloading arch soil pressure calculation and mechanics foundation is natural unloading soil arch action. Its prerequisite is that unloading arch soil pressure all imposes on traversal pipeline after reaming and no buoyancy is considered in the hole. The basic idea is that traversal
pipeline undertakes the collapsing soil pressure and the holding power of bottom of the hole in the process of traction. The pressure of collapsing soil above is calculated according to the height of the natural unloading soil arch\cite{5}, and the empirical formula is as follows.

\[ F_{\text{max}} = f_e L \left( 4D_0 D_e + P_0 \right) \] (1)

Where \( F_{\text{max}}, f_e, L, D_0, D_e \) and \( P_0 \) are pull strength, friction coefficient between pipe wall and pore wall, pipe's length, pipe's outer diameter, maximum diameter of reaming and per unit length of gravity.

Traction power calculation of non-interval drag pipe nitrogen injection for fire control has to be modified as follows: (1) Both maximum diameter of reaming and outer diameter of traversal pipeline are modified into injection nitrogen pipe's outer diameter. (2) Gravity of traversal pipeline per unit length is modified into stress on injection nitrogen pipe per unit length. The formula is as follows.

\[ F = f_e L \left( 4D^2 + q_0 \right) \] (2)

Where \( F, f_e, L, D \) and \( q_0 \) are traction power, friction coefficient between pipe wall and pore wall, pipe's length, pipe's outer diameter and stress per unit length.

By the elasticity theory about the theoretical calculation of thin-walled pipe, the horizontal shear stress on injection nitrogen pipe surface is as follows.

\[ \sigma_\theta = -\frac{D^2}{D^2 - d^2} \left( 1 + \frac{d^2}{D^2} \right) P \] (3)

Where \( \sigma_\theta, d, D \) and \( P \) are surface shear stress, pipe's inner diameter, pipe's outer diameter and external stress on injection nitrogen pipe.

From Formula (3), compressive stresses on nitrogen injection pipe surface is available as follows.

\[ P = -\frac{D^2}{D^2 + d^2} \sigma_\theta \] (4)

Then the load of nitrogen injection pipe imposed per unit length is as follows.

\[ q_0 = P \pi D = \frac{D^2 - d^2}{D^2 + d^2} \sigma_\theta \pi D \] (5)

From Equation (2) and (5), traction power formulas of non-interval drag pipe nitrogen injection for fire control is as follows.

\[ F = f_e L \left( 4D^2 + q_0 \right) = f_e L \left( 4D^2 + \frac{D^2 - d^2}{D^2 + d^2} \sigma_\theta \pi D \right) \] (6)

4. Stress distribution simulation of nitrogen injection pipe

4.1 Establishment of physical calculation model
Taking 8204 work face of YanZiShan mine for example; establish a calculation model which has 400m length, 260m width and 100m height. According to the theory of "O" ring theory, the central deformation is large in the process of excavation. So grids follow the principle of peripheral sparseness and central dense in the whole process as shown in Fig.2 (a)\(^{[9-12]}\). The outside diameter of Nitrogen injection pipe is 4 inch, namely: outside diameter is 144 mm, wall thickness is 5 mm, as shown in Fig. 2(b). The physical mechanical parameters of mining face roof and floor rock is shown in Table 1 and nitrogen injection pipe mechanics parameters is shown in Table 2.

### Table 1 Physical mechanical parameters of 8204 work face roof and floor rock

| Name of roof and floor | Volume modulus B/Pa | Sheer modulus S/Pa | Internal friction angle F/° | Cohesion C/Pa | Tensile strength T/Pa | Density D/kg.m\(^{-3}\) |
|------------------------|---------------------|--------------------|----------------------------|---------------|-----------------------|------------------------|
| Sediment interactive layer | 5.83e8              | 1.89e8             | 33                         | 1.5e6         | 1.0e6                 | 2400                   |
| Main roof              | 7.44e8              | 5.12e8             | 37                         | 8.56e6        | 3.0e6                 | 2500                   |
| Immediate roof         | 6.33e8              | 0.44e8             | 32                         | 1.5e6         | 1.0e6                 | 2400                   |
| Coal                   | 2.08e8              | 0.35e8             | 25                         | 1.0e6         | 0.1e6                 | 1400                   |
| Immediate floor        | 6.94e8              | 5.21e8             | 38                         | 24.6e6        | 3.0e6                 | 2600                   |

### Table 2 Nitrogen injection pipe mechanics parameters

| Volume modulus K/Pa | Elastic modulus E/Pa | Sheer modulus G/Pa | Density D/kg.m\(^{-3}\) | Poisson’s ratio \(\mu\) |
|---------------------|---------------------|--------------------|-------------------------|------------------------|
| 133e9               | 200 e9              | 80 e9              | 7850                    | 0.25                   |

#### 4.2 Numerical simulation results

In the process of excavation, the step distance of model is 20m. Along horizontal direction, it retains respectively 40m protective coal pillars. In the process of calculation, monitor and record the maximal unbalanced force of the system, and judge whether the calculation model is balanced or not. If the model is balanced, proceed to the next step of excavation.

The convergence index of the simulation system uses relative convergence standard, and when the ratio \(R\) is less than \(10^{-5}\) which is the maximal unbalanced force and typical internal force, the model is thought to be balanced state, and then the calculation stops. Because with continuously advancing of the work face
and gradually compacting in goaf, the load stress of overlying strata is the largest which is upon the end of nitrogen injection pipe. And the stress distribution state is shown in Fig.3. The stress upon the end of nitrogen injection pipe mainly comes from the horizontal direction. The Fig.3 (b) shows that the top and bottom of nitrogen injection pipe will meet stress concentration. The maximum horizontal stress is $5.1149 \times 10^4 \text{Pa}$.

Fig.3 (a) End section stress distribution on horizontal direction    (b) End section stress distribution on vertical direction

4.3 Traction power calculation

From Formula (6), it is known that the traction power of non-interval drag pipe nitrogen injection for fire control is as follows.

$$F = f_c L (4D^2 + q_o) = f_c L \left( 4D^2 + \frac{D^2 - d^2}{D^2 + d^2} \sigma_o \pi D \right)$$

Select: $\sigma_o = 5.1149 \times 10^4 \text{Pa}$, $f_c = 0.3$, $L = 50 \text{m}$, $D = 0.144 \text{m}$, $d = 0.104 \text{m}$.

Calculated: $F = 30.1 \text{KN}$.

5. Conclusions

(1) According to the principle that nitrogen injection pipe’s shear performance is better than its tensile performance, the process of non-interval drag pipe nitrogen injection for fire control is designed in the way of rotation traction.

(2) The specific design scheme is improved of non-interval drag pipe nitrogen injection for fire control.

(3) Based on the unloading arch principle and the calculation of drag force in pipe directional crossing technology, traction power calculation formula is obtained for non-interval drag pipe nitrogen injection for fire control.

(4) Stress distribution is simulated of the end cross section of nitrogen injection pipe in goaf in YAN ZI SHAN mine. The stress which is acted on the nitrogen injection pipe ends mainly comes from horizontal stress of the overlying strata and the top and bottom will meet stress concentration.

(5) According to the results of the simulation, traction power is calculated for non-interval drag pipe nitrogen injection for fire control.

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