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Research Article

Application of Free Ball Check Valve Mixed Grouting Device

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Abstract

In recent years, due to the uneven water abundance of the aquifer and the complexity of the underground seepage field, the grouting reconstruction project of coal mining enterprises is more difficult. The previous method is to install a high-pressure ball valve before the grouting pipe connected to the grouting pump is connected to the mixing device, which can be manually adjusted when the number of grouting pumps needs to be changed. However, under certain pressure, the ordinary high-pressure ball valve often fails due to the influence of high-pressure mixed slurry, cement solidification and wear, and the number of grouting pumps cannot be increased or decreased in real time. In order to solve the problem that the mixing device of traditional grouting system is easy to fail by using ordinary high-pressure ball valve, the mixing device of free ball check valve was developed and applied in the process of treating the Ordovician limestone aquifer area on the floor of No.9 coal seam in Xipang Well. The practical results show that the pipeline can be automatically closed when a single grouting pump stops grouting, and there is no need to flush the grouting pipeline with a large amount of water, which can improve the grouting efficiency and quality, and the influence time of single hole section is reduced from 8.25h to 0.34h. The process performance can meet the requirements of efficient grouting.

Keywords

Directional Drilling Rig, Regional Governance, Grouting Transformation, Free Ball Check Valve, Mixing Plant

1. Introduction

Many coal mines in China are threatened by water damage in the confined aquifer of the floor, especially in the Ordovician limestone confined aquifer in North China. Due to the large thickness of the aquifer, strong water richness, abundant supply, high water pressure, and close distance from the mining coal seam, once the water is discharged, it often leads to serious water damage accidents, resulting in significant personal casualties and property losses [1]. At present, the treatment of confined aquifer in the floor has developed from suspected exploration to excavation and exploration, from geophysical difference, drilling verification, grouting transformation to full floor grouting reinforcement [2]. In the early stage, due to the backward technology, drilling and grouting work was mainly carried out in the bottom rock roadway of underground construction, but there were shortcomings such as long period, poor safety, complex process and low efficiency [3]. In recent years, with the popularization of directional drilling rigs, more and more coal mining enterprises have adopted the method of pre-grouting in the area of ground directional bedding multi-branch drilling to transform the floor aquifer. After years of practice and improvement, the directional drilling rig has been very mature [4]. However, due to the uneven water-richness of the aquifer and the complexity of the underground seepage field, it is often difficult to recon-

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struct the grouting project. Especially in the strong water-rich area, the crack (dissolution) gap is more developed, and a single leakage point (section) may consume thousands of tons or even tens of thousands of tons of dry material. It is necessary to use multiple high-power grouting pumps to meet the grouting demand at the same time. In each stage of grouting transformation, the number of grouting pumps needs to be adjusted in real time according to the grouting effect. The previous method is to install a high-pressure ball valve before the grouting pipe connected to the grouting pump is connected to the mixing device, which can be manually adjusted when the number of grouting pumps needs to be changed. However, under certain pressure, the ordinary high-pressure ball valve often fails due to the influence of high-pressure mixed slurry, cement solidification and wear [5-8], and the number of grouting pumps cannot be increased or decreased in real time. At this time, it is necessary to release the pressure of the grouting system before the operation, but the unplanned stop of injection during the grouting process may lead to the failure of the early grouting, affecting the grouting effect, and the process is complex, time-consuming and laborious. In order to solve this problem, the design of new multi-pump high-pressure grouting self-mixing device is carried out in engineering practice, and good application results are obtained [9-12].

2. Design of Grouting Mixing Device

2.1. Grouting Mixing Device Definition

During the high-power grouting period, multiple grouting pumps need to be opened at the same time. The grouting pipeline of the grouting pump needs to be connected to a container first, and then the grouting pipe sends the slurry into the directional borehole to grout the target aquifer. The container is defined as a mixer, which can have multiple inlets and one outlet, and can be combined with a control valve to form a grouting pipeline mixing device.

2.2. Analysis of Problems in Traditional Schemes

The traditional grouting system consists of several grouting pumps, supporting grouting pipelines, ordinary high-pressure ball valves, and slurry mixers. Multiple grouting pumps are connected to the mixer through a grouting pipeline equipped with a high-pressure ball valve. The slurry is mixed in the mixer and sent to the target well. There is a pressure gauge (or pressure sensor) on the top of the mixing device to monitor the slurry pressure in the mixer in real time. In practice, ordinary high-pressure ball valves often fail due to the influence of high-pressure mixed slurry, cement solidification, wear and tear.

When the traditional mixer is used for construction, all grouting pumps and mixers are connected by ball valves. When the pressure is constant, under the combined influence of high-pressure slurry and cement consolidation, the high-pressure ball valve is prone to failure, resulting in failure to close. At this time, the grouting pump will be connected to other pumps. When adjusting the grouting volume to close a grouting pump or repair the damaged grouting pump, it is necessary to flush the grouting pipeline with clear water to prevent pipeline blockage, close all the grouting pumps and release the grouting system before closing the target ball valve or withdrawing the grouting pump. Once the ball valve jam occurs, the high-pressure ball valve must be removed and the matching plug must be installed in order to continue the next step. When replacing the grouting pump or replacing the accessories when the grouting pump is damaged, it is also necessary to repeat the above processes such as water flushing, closing the grouting pump, and pressure relief of the grouting system [13-15].

In the specific grouting practice, it is found that the traditional mixing device operation is prone to the following problems:

(1) During the grouting process, the mixing device is in a high-pressure state. If the high-pressure ball valve is manually operated, there is a certain safety hazard; (2) Under the condition of high pressure ball valve failure, adjusting and replacing the grouting pump requires more manpower, and the pump stops for a long time, which affects the grouting speed. (3) When adjusting and replacing the grouting pump, it is necessary to clean the grouting system with a large amount of water to prevent the grouting pipeline from blocking, which causes the grouting slurry to be diluted and forms uncontrollable factors. (4) Due to the long time of adjusting and replacing the grouting pump and the flushing grouting system, the unplanned stopping injection has a negative impact on the grouting effect. (5) When the system before the mixer fails and needs to be repaired, the above problems also exist. Based on this, the mixing device of grouting system using ordinary high-pressure ball valve will cause each grouting pump to interact with each other and lose independence when a single part needs to be adjusted, which is contrary to the original intention of installing high-pressure ball valve.

2.3. Design of Free Ball Check Valve

In order to solve the problem of subsequent construction difficulties caused by the failure of traditional high-pressure ball valves, the problems existing in the process of ground directional long-hole area treatment in Xipang well are analyzed, and the device is improved. The free ball check valve is designed to replace the traditional high-pressure ball valve, which greatly improves the process performance of the mixing device of the grouting system.

(1) Structure: the free ball check valve includes valve body, upper and lower end cover and a steel ball. The lower end cover contains the inlet of the one-way valve, the valve body

contains the outlet of the one-way valve, the bottom of the upper end cover is welded with the limit bar, and the inner bottom of the valve body is processed by the ball seat. Before closing the upper end cover, the steel ball is put into the valve body. The ball valve is composed of the steel ball, the ball seat and the limit bar, which can avoid the steel ball blocking the outlet of the one-way valve. The upper and lower end covers of the check valve are fastened and sealed by high-strength bolts and sealing rings.

(2) Operation principle: the check valve is installed vertically, and the ball valve is in a normally closed state. When the grouting is started, the high-pressure slurry pushes the steel ball up, and the slurry enters the valve body. Under the action of the limit rod, the check valve outlet is always in a normally open state, and the slurry can flow freely. When the amount of slurry eaten becomes small, the steel ball will fall downward under the action of gravity. When the grouting is stopped, the steel ball falls into the ball valve seat, and the check valve is closed under the reverse pressure of the slurry.

2.4. Design and Installation of Free Ball Check Valve Mixing Device

Before the grouting pipe of the grouting pump is connected to the mixer, a free ball check valve should be installed. The front end grouting pipe of the check valve and the back end slurry mixer should be installed with a pressure relief valve to complete the segmented pressure relief function. The mixer also installs a pressure gauge (or pressure sensor) to monitor the grouting pressure in real time.

The mixing device of free ball check valve mainly includes free ball check valve, mixer, pressure gauge and pressure relief valve. The operation principle is as follows: at the beginning of grouting, the free ball check valve is opened under the action of high pressure of slurry, and the slurry enters the target well from the outlet after passing through the mixer. After stopping grouting, the free ball check valve is automatically closed under the action of gravity. When it is necessary to close a grouting pump, the principle is the same as above. The device structure is shown in Figure 1.

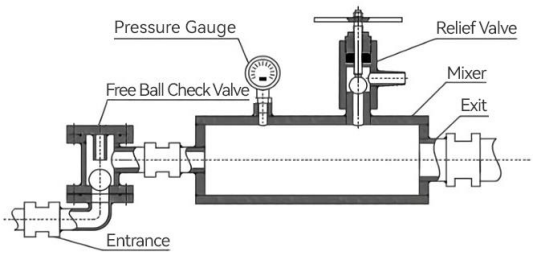

Figure 1. *Free ball check valve mixing device structure design.*

The free ball check valve mixing device is shown in Figure 2. The device has the following advantages:

(1) During the grouting period, the steel ball in the one-way valve vibrates and rotates under the action of fluid, which can effectively delay the solidification of the slurry. The process performance is good, and it realizes automatic control without manual operation and eliminates safety hazards. (2) The free ball check valve is simple in structure, easy to install and maintain, and closes tightly under the back pressure of the slurry after stopping the pump; (3) During the grouting operation, the pump can be stopped at any time when the number of grouting pumps is adjusted or the grouting pump is repaired, which does not affect the operation of other grouting pumps, avoids unplanned stopping of grouting, and improves the grouting efficiency and grouting quality. (4) Before stopping the pump, only the single-pass grouting pipeline of the front system of the mixing device needs to be cleaned for no more than 2 minutes, which has little effect on the slurry concentration; (5) The pressure relief valve is installed to relieve the pressure of the grouting system in sections, which enhances the safety of the grouting system.

Figure 2. *Free ball check valve mixing device.*

3. Comparative Analysis of Application Effect

3.1. Project Profile

The Xipang well of Dongpang Mine belongs to Jizhong Energy. The target layer of the pre-treatment project for the aquifer area of the coal seam floor of the ground directional long borehole is the Ordovician limestone confined aquifer. The vertical range is 25 m below the top interface. The plane range is the 9 # coal seam floor elevation of the mine-280 ~ 460 m area. A total of two ground main holes are designed, which are No.1 hole and No.2 hole, and the two ground main holes are respectively equipped with grouting stations. There are 6 horizontal branch boreholes in No.1 hole, the total drilling footage is 6853 m, and the total grouting amount is 52114 t. There are 22 horizontal branch boreholes in No.2 hole, the total footage is 17445 m, the total grouting amount is 115016 t, and the spacing of horizontal branch boreholes is 40 m. The total footage of the project is 24298 m, and the total grouting amount is 167132 t.

3.2. Grouting Technique

In the regional control project of Ordovician limestone aquifer in 9 # coal seam floor of Xipangjing Coal Mine, two long directional boreholes were designed on the ground, and one grouting pumping station was built for each borehole. In this station, three mud pumps of NBB-390 / 15 are installed, two are used and one is prepared, and one auxiliary mud pump of NBB260 / 7 is used before the end of grouting. The parameters of the two grouting pumps are shown in Table 1 and Table 2.

Table 1. *Parameters of NBB-390 / 15 mud pump.*

Transmission Gear	1	2	3	4	5
Rated Flow (m³/h)	3	5.5	10.2	15	23.3
Rated Discharge Pressure (MPa)	11	11	11	11	8

Table 2. *Parameters of NBB260 / 7 mud pump.*

Transmission Gear	1	2	3	4	5
Rated Flow (m³/h)	1.7	2.7	4.6	7.5	11.2
Rated Discharge Pressure (MPa)	10	10	10	10	7

Before grouting, the water pressure test is first carried out, and the initial flow rate is set according to the test results. In the case of no pressure, the initial flow rate is set to 15m^3/h; when the pressure is stable, the grouting is carried out according to the stable pump volume. After grouting 1h according to the initial flow rate, if the pressure changes little, the flow rate can be gradually increased until 30m^3/h. When the grouting pressure is steadily increased, the grouting flow should be maintained to increase the pressure to the design pressure. When the grouting pressure continues to rise more than the design pressure, the flow should be gradually reduced. When the double pump of NBB-390 / 15 grouting pump reaches the grouting pressure, one mud pump is withdrawn, and the single pump grouting is started. When the design pressure is reached again, the NBB260 / 7 grouting pump is used for grouting. When the pressure and flow rate reach the end standard, the grouting is stopped.

3.3. Comparative Analysis of Application Effect

(1) Traditional mixing device

In this grouting reconstruction project of floor aquifer, 10 bedding branch holes have been constructed, among which ground 1-1, ground 1-2, ground 1-3 and ground 2-1, ground 2-2, ground 2-3 and ground 2-4 grouting systems adopt traditional mixing devices. The pump removal (replacement) and maintenance during the on-site construction process are shown in Table 3.

Table 3. *Influence of traditional mixing device grouting system.*

Hole Number	Length of hole section (m)	Number of grouting sections	Pump withdrawal (change) times	Frequency of maintenance
Ground 2-1	687	5	10	11
Ground 2-2	414.06	3	6	7
Ground 2-3	684.87	5	10	10
Ground 2-4	767.87	6	12	11
Ground 1-1	1062.17	8	16	18
Ground 1-2	966.21	7	14	15
Ground 1-3	851.83	6	12	13

Hole Number	Length of hole section (m)	Number of grouting sections	Pump withdrawal (change) times	Frequency of maintenance
Total	5434.01	40	80	85

It can be seen from Table 3 that 7 branch holes are constructed by using the traditional mixing device grouting system, a total of 5434.01 m. The pump is removed (replaced) and the maintenance situation is 165 times. The single replacement is calculated according to 2h, and the total time is 330 h. The average influence of each grouting section is 4.125 times, and the average time is 8.25 h.

(2) Free-ball check valve mixing device

The three branch holes of ground 2-5, ground 2-6 and ground 2-7 adopt the free ball check valve mixing device grouting system. During the period, when the pump needs to be removed (replaced) or repaired, only the front (including) pipeline of the free ball check valve needs to be rinsed for 3-5 minutes, and the grouting pump can be stopped at any time. The pump removal (replacement) and maintenance during the on-site construction process are shown in Table 4.

Table 4. *Influence of grouting system of free ball check valve mixing device.*

Hole Number	Length of hole section (m)	Number of grouting sections	Pump withdrawal (change) times	Frequency of maintenance
Ground 2-5	1331.02	9	18	16
Ground 2-6	598.67	4	8	10
Ground 2-7	682.68	5	10	12
Total	2612.37	18	36	38

It can be seen from Table 4 that three branch holes are constructed by using the traditional mixing device grouting system, a total of 2612.37 m. The pump is removed (replaced) and the maintenance situation is 74 times. The single replacement is calculated according to 5 min, and the total time is 370 min. The average influence of each grouting section is 4.11 times, and the average time is 20.6 min.

3.4. Benefit Analysis

From Table 3 and Table 4, it can be seen that when the grouting method and grouting process are the same, the difference of the mixing device has basically no effect on the number of pump removal (replacement) and maintenance, and each grouting section is more than 4 times, but the influence time of the grouting system of the free ball check valve mixing device is shorter, which is reduced by 7.91 h / time. According to the remaining footage of 16251.62 m, that is, no less than 90 grouting sections, the use of free ball check valve mixing device will save 711.9 hours.

4. Conclusion

According to the operation principle of the pressure relief valve, the free ball check valve mixing device is designed to replace the traditional high-pressure ball valve. It can be automatically closed when the grouting is stopped. When the pump needs to be removed (replaced) and repaired and maintained, the grouting pump can be stopped at any time, which saves a lot of time, reduces the safety risk and improves the grouting efficiency. After using the free ball check valve mixing device, when the grouting pump is shut down, there is no need to wash the grouting pipeline with a large amount of water, which has little effect on the slurry concentration, and at the same time, the unplanned stop injection is eliminated and the grouting quality is improved. The free ball check valve mixing device has simple structure, convenient installation, reliable performance and long service life. It shows good process performance in practice, and has high economic benefits and can be popularized and applied.

Author Contributions

Yifang Liu is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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