Analysis on the Security Monitoring and Detection of Mine Roof Collapse Based on BOTDR Technology

Shuai Wang

School of Information Science & Technology, Qingdao University of Science & Technology. Fuxin, 123000

Lijun Luan

School of Mechanical Engineering, Liaoning Technical University, Fuxin, 12300

Abstract--**Mine roof collapse is always the top issue of mine security, and apparently traditional detection methods don't have a very good performance. In this thesis, the authors present the detection performance of BOTDR technology to mine roof. The authors bring up corresponding wiring technology and methods according to different roof structures, achieving the all-around and real-time inspection from points to line, from the line to the surface, so as to improve the accuracy and safety of the monitoring of mine roof.**

Keywords: BOTDR; Roof; Stress Comprehensive Monitoring; Real-time Monitoring; Mesh Structure

I. INTRODUCTION

Roof collapse is always the top issue of China's coal mine safety. Although its loss is smaller compared with other coal mine accidents, due to the high frequency of its occurrence, roof collapse still causes significant losses to China's coal mine. With incomplete statistics, roof collapse accounts for 55% of all mine accidents.

Though there are many reasons may cause the roof collapse, the fundamental one is the mine stress activities in the mining process. Varying degree of deformation occurs to the mine roof due to the stress activities, which appear as cracks along with the roof section manager and separation generated. By this time, layers broken, partial roof collapse will happen when the deformation of rocks exceed the elastic deformation if the management is not proper, the quality of supporting is not good. If we analysis the causes of roof collapse, the authors find that some are due to the limited understanding, but meanwhile, mostly are due to the improper field management. Here is the specific analysis:

(1) Lacking of vigilance and careless are the ideological root of roof collapse. Be vigilant is an important experience to prevent accidents and ensure the mining safety. After goes down the mine well, the operator shall be concentrated and first check the safety situation, and inspect the insecure phenomenon carefully. Avoiding to solve problems and troubles, and don't implement the rules and regulations are the roots of accidents.

(2) The complex geological structure is an important factor of the accident. The structure of geologic fault and folds zone are much destroyed and easily collapse. When the initial and cyclical stress comes, the quantity and speed of roof subsidence are sharply increased, and the stress of supporting soared. The mine roof becomes broken and there is a huge risk of roof collapse. If we don't well know the existing conditions, nature and changing circumstances, we cannot take the right measures.

(3) Illegal operation is the direct cause of roof collapse. The roof collapse can be prevented effectively providing the strict and careful preparation and implementation of operation regulation, according to the different geological data. Operation regulation contains the different mining method, safety measures, ventilation method, supporting method, quality and other specifications according to different geologic conditions. Roof collapse can be easily occurred if the operation surface is not straight, supporting is not installed as requirement, empty roof is huge or the supporting tool is removed.

(4) Roof collapse due to irregular operation. The remining speed of operation site is faster with less stress on the mine roof with regular operation; otherwise, the speed of operation is slower with big stress to the mine roof

II. PRESENT SUPPORTING METHODS OF MINE ROOF AND ACCIDENTS CAUSES

The present supporting methods and tools of the mine roof are rather complete. According to different roof structures, different supporting methods and tools are used. But there are still many roof collapse occurs, because of the complex and changeable underground environment, and the mine roof has natural descending and deformation.

Without the all-around real-time monitor to provide data, the good supporting tools and methods cannot work well. Besides the operation error and carelessness, the limitation to the monitoring method is the main cause of the roof collapse. Single point and distributed measurement is mainly used in the traditional roof monitoring method. But with the high costs, this kind of measurement cannot realize the all-around and real-time monitoring and inspection to the whole roof. Using the light as the sensor, the new measurement based on BOTDR technology can achieve all-around and real-time monitoring and inspection to the mine roof, so as to provide a full range of data to improve the safety of mining.

III. PRINCIPLES AND PROCESS OF BOTDR STRAIN MEASUREMENT

BOTDR strain measurement is a measurement and monitoring to the transformation of optical fiber by the light

of the linear relation between Brillouin scattering light frequency shift and stress. The measurement principle is shown in Figure 2.1.
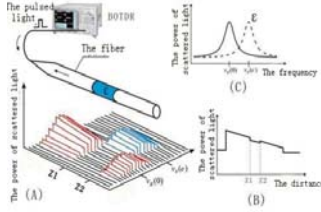

Fig.2.1 Strain measuring principle of BOTDR

The purpose of BOTDR strain measurement is to calculate the distance between the random point on optical fiber to the incidence end, as well as the strain of optical fiber. The operation method is using the BOTDR machine to monitor and inspect the optical fiber strain gage percentage, and make alarms when the percentage exceeds certain degree and then calculate the detailed position. The measurement process is:

Probe pulse with a certain frequency of light from the fiber end of the incident acoustic phonon interaction in the incident pulse and fiber Brillouin scattering, the backward Brillouin scattering of light along the fiber the same route to return to the pulsed light incident side, enter BOTDR by the optical part and the signal processing unit, through a series of signal processing can be astigmatism power of the fiber along the Brillouin frequency of the probe back. The distance Z between any point on fiber and fiber end can be calculated by the formula (2.1):

$$Z = \frac{c \cdot T}{2n} \qquad (2.1)$$

C refers to the light speed in vacuum, n refers to the refractive index of optical fiber, T refers to the interval between the impulse light and the scattered light delivered.

After that, according to the frequency of the incident pulse of light within a certain interval of changing, optical fiber can be obtained of each sample point on the Brillouin gain spectrum backward scattering (the Brillouin gain spectrum).

After the removal of temperature, axial strain and fiber Brillouin frequency shift of scattered light can be used formula (2.2) to show:

$$V_B(\varepsilon) = V_B(0) + \frac{d V_B(\varepsilon)}{d\varepsilon}\varepsilon \qquad (2.2)$$

$V_B(\varepsilon)$ is Brillouin scattering frequency when optical fiber tensile in axial direction; $V_B(0)$ is Brillouin scattering frequency when optical fiber has no tensile in axial direction; $\frac{d V_B(T)}{dT}$ is gauge factor; ε is optical fiber's tensile in axial direction. The gauge factor depends on the wave length of probe light and the type of fiber used, which needs to be calibrated before the test.

Another prominent advantage of Brillouin scattering of light compared with others is the change in its frequency

shift with temperature-dependent ratio is much smaller strain correlation (0.002% / ℃). Therefore, if the temperature does not exceed 5 ℃, it can usually be ignored. However, when large temperature changes, we can along with type (2.3) for temperature compensation:

$$V_B(\varepsilon) - \frac{d V_B(T)}{dT}(T - T_0) = V_B(0) + \frac{d V_B(\varepsilon)}{d\varepsilon}\varepsilon \qquad (2.3)$$

Among them, $\frac{d V_B(T)}{dT}$ is the temperature coefficient; $T - T_0$ is the variable quantity of temperature；Other is the same as type (2.2)

At present, AQ8603 Fiber Pressing Analysis Machine made in Japan is mainly used in China as the BOTDR monitoring equipment, which can monitor up to 80KM fiber's strain, and its measurement range can up to ± 1.5%, while the measurement accuracy is up to 0.003% with 1 meter of space resolution of 1meter. All the specifications can fulfill the requirements of project safety monitoring and inspection.

A. Advantages of BOTDR Measurement Technology

Single point and distributed measurement is mainly used in the traditional roof monitoring, which can only realize sing point measurement. But aimed at more complex underground environment, we need more all-around measurement data. Based on BOTDR measurement technology, optical fiber sensor can realize the real monitoring and inspection to the line from point, and from line to field. The grid wiring method can be used in the roof needs to be measured. Applying this measurement method, we can obtain more specific data and realize real-time and all-around monitoring and detection to the mine roof, so as to improve the mining safety.

B. The Attached Method of Optical Fiber of Sensor

Applying to the BOTDR technology, the fiber sensor can be planted within or on the surface of the rocky structure. There are two attached methods, including partially attached and fully attached. Find in 3.1
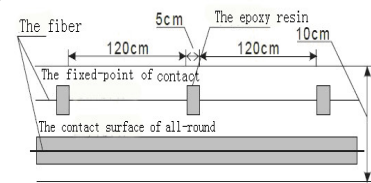

Fig.3.1 Partially attached method and fully attached method

Then after a comprehensive way is to straighten the fiber, the fiber is completely attached using an adhesive on the surface of the test engineering structures, can be approximated that of the sensing fiber and then synchronize structural deformation, this paste is mainly used in the tunnel the whole way deformation monitoring; pointing the way followed by the sensing fiber is properly applied after a certain pre-strain, according to a certain point and then at intervals measured surface works, then you can get two

points between the deformation of the main methods used to monitor deformation laying large local deformation. According to the optical fiber grid and practical situation, adopting appropriate then way each part of laying optical fiber sensor.

C. Fiber mesh structure

Optical fiber sensor design is to adopt the basic requirements of single fiber grid laid, and each corner should comply with the grid fiber materials and optical properties can not have 90 degrees orthogonal turning and reduce corner quantity; at the same time, must strive to achieve monitoring accuracy and facilities cost balance.

For a relatively simple below the surface of the tunnel structure, design a kind of optical fiber grid structure, adopt comprehensive then way laid.

Then using a comprehensive approach is designed to monitor the implementation of comprehensive monitoring object roof, retaining part of the monitoring results for the deformation of the entire roof surface.

Comprehensive and then used particular laid technology, using experiment measure effect excellent mixed with epoxy adhesive (mainly), optical fiber sensing according to design the circuit will then in concrete surface, and in the end of the fiber optical fiber sensing terminal, pick up fiber terminal box can provide more than the fiber optic combiner placement and the optical fiber storage space, give fiber and its components machinery protection and environmental protection, and can make the light fiber optic components and fiber end shell, and can easily be insulation it, then grounded.

In practical projects, it can choose by optical terminal box as a fiber optic combiner to optical fiber protected, also can set fiber end derivation grounded.

After the completion of all the fiber optic sensor as in the roof laying a big net Lu will cover all roof, and each grid is a surface pressure detector. System structure is shown in figure 3.2.

This kind of optical fiber grid specifications to the current domestic mainly adopts the BOTDR monitor AQ8603, for example: the maximum range resolution for AQ8603 1-m, to enable each grid occurred within the four grid strain when the optical fiber sensor are afraid to strain, improve measuring sensitivity, grid side as the 1-m, this also basic can satisfy the tunnel engineering to monitor resolution requirements.
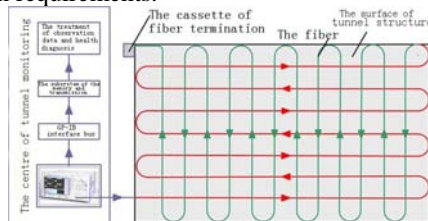

Fig.3.2 BOTDR optical fiber strain monitoring system for grid

D. Monitoring Principle of Optical Fiber Grid Structure.

This structure has many advantages particularly in the aspect of measurement accuracy. The design of grid structure has fully improved the speed and accuracy of the measurement and inspection to the stress points.

First, we give number to each grid, which means to number the stress probe of each surface, as shown in Figure 3.3. During the process of roof strain gage monitoring, when there is a dangerous optical fiber strain gage in the axial direction, the BOTDR equipment will point out the one or many grids with strain gage happening; The specific geographic strain gage point can be located by field inspection and measurement, which realizing the measurement and inspection from point to surface, and then from surface to the point.

Fig.3.3 Optical fiber grid code

From Figure 3.3, the simulated fiber mesh size is 13 * 8. Among all the 104 grids, in addition to the outermost grid, each grid is composed of two vertical and horizontal composition of two fiber optic sensors. This design can fully separate the 4 strain gage signals which are reflected by optical fiber sensor in different time so as to improve the measurement accuracy and, the positioning to the strain points can be faster. Here is Figure 3.4.

Figure 3.4 shows four optical fiber strain points (Strain point 1 - 4) are generated due to the strain gage in the roof surface within the grid in D7. The time of the signals are fully separated because the adequate distance among the four points on the whole optical fiber sensor. With more specific data, the four strain points can be easily positioned within Grid D7 according to the relationship between signals and optical fiber grid. Meanwhile, the strain points on the surface of mine roof can be positioned according to the grid position of four summit points of optical fiber strain.
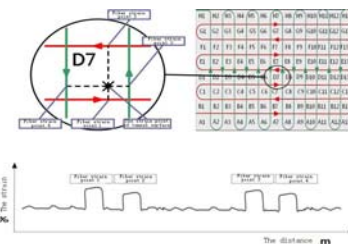

Fig.3.4 Optical fiber strain measurement principle of the grid

E. Mine Roof Monitoring and Inspection on the base of BOTDR technology

Different methods of wiring shall be applied according to the different structure of roof. Combined with the actual geological conditions, the comprehensive attached and fixed-point attached methods of wiring are suitable for the

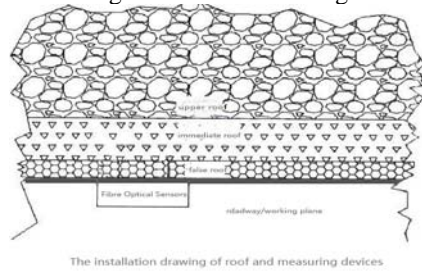roof of mine. Wiring method shown in Figure 3.5

Fig.3.5 Mine Roof fiber optic wiring

The roof of the mine is mainly constituted by the original roof, direct roof and fake roof. The real-time monitoring to the strain of the mine roof can be realized with the optical fiber sensor on the surface of the fake roof, and no need to be attached inside the roof. In this way, the damage to the roof structure by wiring can be reduced, as well as the impact factor to the roof safety. But we shall note that the optical fiber must be attached with the roof completely when wiring which can ensure the accurate results of the measurement. At the roof with complex structure, the optical fiber can be attached in the flat woods. In this way, the wiring within rather complex environment can be finished.

Meantime, combined the present mine all-around monitoring program, the optical fiber sensor presents a brand new system on the base of BOTDR technology.
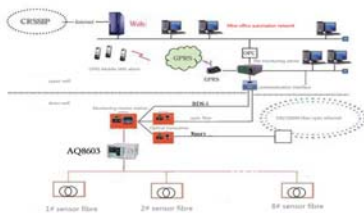

Fig.3.6 all-around monitoring program

IV. DISCUSSION OF WIRING METHOD

We have to consider the wiring method of fiber optical sensor considering the rather complex underground environment and large humidity. Two wiring methods like partially attached method and fully attached method, are mainly used to the smooth surface. But aimed at the complex underground environment, different wiring methods shall be applied in different environments. First, for the rather flat roof, wiring of fully attached method can be applied. For the characters of optical fiber sensor, the embedded wiring method can be applied. Open a slot on the surface of the roof, and the width of the slot shall be a litter bigger than that of optical fiber. Then pour the optical fiber and the adhesive materials which mainly is silicon carbide

into the slot, which can give a effective buffer to the optical fiber. The adhesive materials suit the humid environment, and have certain flexibility after its solidification. In this way, the optical fiber can be protected to some extent without affecting the detection accuracy. Secondly, aimed at the roof with rather complex geographical environment, the referred two wiring methods can be combined. Aimed at the low and humid condition, we can fix woods in the low and humid spot first, and contact them with the roof completely, and then place the fiber optical sensor on the woods. Aimed at the rocky parts of the roof, we can choose wraparound wiring method, which means bypass the uneven area or rocks when wiring.

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