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Application of Distributed Fiber Temperature Detection Technology in the Shaft Freezing Restoration Project

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Abstract

According to the particularity of the restoration project of using freezing method to conduct shaft-forming well wall, the monitoring of the conventional hydrological hole and thermometer hole, new means of detection are added, and distributed fiber temperature detection technology is used to check the temperature of each longitudinal freezer. The principle, composition, detection method and temperature measuring optical cable structure of the distributed fiber temperature detection system are introduced in detail. Field measured data is given, which has large data size and can reflect the actual development status of freezing wall comprehensively and intuitively compared with the traditional thermometer hole data. Data analysis provides the basis for guiding the freeze construction being carried out safely and smoothly. The structure of system is simple and flexible, and the detection method has a certain promotional value.

Keywords: *distributed fiber temperature detection, freezing method, longitudinal temperature detection, restoration project*

1. Introduction

Artificial freezing method is a commonly used method in the construction of the shaft, now the frozen depth is about 700m, the design of freezing scheme; the process control technology has been matured. In the general freezing engineering, in the freezer coil diameter inside, it is decorated with a few thermometer holes and hydrological holes, according to each point in the thermometer hole, the situation of the frozen wall temperature can be obtained, and according to the situation of hydrological hole, the water-bearing strata frozen wall whole circle can be judged [1, 2]. But the freezing method is adopted to repair wellbore and the detection method can not meet the needs of freezing, thermometer hole can only reflect the local situation of shaft freezing, hydrological hole overflow water can not be the judgment conditions of the frozen wall/circle. In this particular case, in order to grasp the development situation of the frozen wall fully, and control the thickness of frozen wall effectively, the distributed optical fiber temperature measurement technology can be adopted to detect the longitudinal temperature of freezer, and more intuitive observation development of frozen wall can be realized [3, 4].

2. Project Summary

Banji mine belongs to investment xinji energy co., LTD. It is the new large mine, wellbore diameter design of the Lord, vice, and the wind is 6.2m, 7.3m and 6.5m respectively, the depth of the shaft are 795.5m, 795.4m and 776.5m. In Its thick overburden section, it adopts the drilling construction, drilling depth are 660m, 640m and 656m respectively. Ground precast reinforced concrete and double steel reinforced concrete composite wall structure are adopted, special slurry-supported; suspended docking sink, water wall of mud and rubble after cementing filling construction technology are also adopted, etc.

The shaft drilling of Banji well is since December 29, 2004, in early October of 2007 the shaft sinking and wall filling are completed, at the end of 2007, the bottom of the pot into the bedrock section of the common law construction is carried out, June 8^{th} the wellbore

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construction is finished. Due to bottom hole cavern group of difference of lithology, the ingate flanks pressure appeared obviously, it is repaired for 6 times. On April 18, 2009, the water inrush accident is appeared, till April 22, the coal mine during water depth is about 20.7 meters, the main well water depth is 13.85 meters, and the wind well water depth is 121.1 meters. Main shaft top boundary depth is 612 meters, during sediment depth of 590 meters, the wind well sediment depth is 670 meters; According to the main shaft sediment depth estimation, water inrush current sediment concentration is 17.3%; through analysis and calculation, water filling capacity is 76744m^3, under three separate shaft water filling capacity is 22926m^3, it is 5 hours 20 minutes since the accident happens, the average yield is 18700m^3/h.

After the accident, according to the sand and rock composition of inrush water, and judge the wall outlet point above the bedrock weathering zone area; Through the analysis of the groundwater level observation hole, if the three above aquifer water level did not change, four including water level changes obviously; wellbore water inrush water can be judged from four or four aquifers below. Through using borehole color television meter, and the ultrasonic tool, but they are proved not the effective method in judging water point location and the wellbore fracture situation; when the average yield is about 18700m^3/h, we can judge the damage scope is big. Finally we decided to adopt the ground pregrouting and freezing method to repair wall, after the grouting method is used in improving the soil and shaft wall fillings performance, the method of frozen water sealing repair wall is also adopted, frozen wall should have certain strength and thickness.

During the construction of total nine injection holes and one validation hole, since April 23, 2009, till May 31, 2010, the work is lasted for 403 days, 76708m^3 cement are filled into the ground, and the total consumption is 74604.45 tons.

During auxiliary shaft construction, its freeze depth is 673m, in order to make quick freezing wall ring, quickly to meet the design thickness, enhance resistance strata disturbance after the ability of other risks brought by the weakening performance, the double row holes arrangement are adopted. In order to reduce the frost heaving force affect wall, hole layout should be as small as possible in the circle diameter. Outside decorating the is 42 freezing holes, decorate circle diameter is 19.6m, hole spacing is 1.465m. Row layout is 32 freezing hole, the decorated circle diameter is 13.9m, hole spacing is 1.364m, the number of thermometer hole is 7, the number of hydrological hole is 4. Arrangement of freezing hole is as shown in Figure 1.

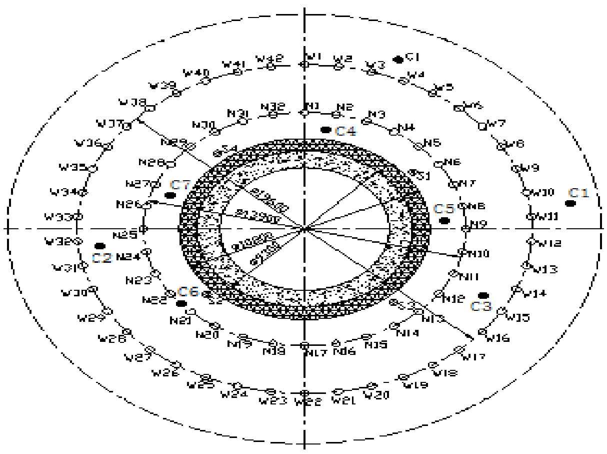

Figure 1. Layout of Auxiliary Shaft Frozen Hole

During June 27, 2011, boot operation, as of September 11, during all four hole water levels reach the nozzle, from the analysis of the water level change of the each development of frost heave water freezing wall, part of the frost heave pressure through the analysis of hydrological hole was released. Because of the freezing method is applied to supplying wall repair engineering was the first time; there is no experience to draw upon. At this point, through the analysis of hydrological hole water and the thermometer hole data can't accurate judgment whether the freezing wall to circle and its development.

On November 8, 2011, the frozen engineering works for 131 days, brine temperature is between -32~-33℃, the temperature difference is between 2.5~3.8, construction organization design requirements is about for 150 days, the 19 days is remained. In order to grasp the actual situation, construction plan is formulated; the construction of stones wellbore should be as soon as possible, and the longitudinal temperature measurement should be carried out.

3. Test System

3.1. Detection Principle

Distributed optical fiber temperature measurement system in the whole temperature measurement on the length of the fiber optic cable, with a certain interval continuous perceive the change of temperature field in the fiber length direction. Measuring principle is optical time-domain reflectometer (OTDR) theory and backward Raman scattering (Raman) temperature effect, the time domain reflection principle is adopted which can realize the temperature measuring of the point location, through backward Raman scattering principle can realize the perception and measurement of temperature.

From the perspective of quantum theory level, Raman scattering is produced by photons of inelastic collisions. In the experiments, it is found that Anti Stokes scattering light is sensitive to temperature, the strength is modulated by the temperature; Stokes scattering light intensity also has a certain relationship with the temperature, but the influence of temperature is small; The Rayleigh scattering light has nothing to do with the temperature.

In the area of optical fiber L, the number of antistokes scattering photon is as (1).

$$N_a = K_a S \nu_a{}^4 N_e \exp[-(a_0 + a_a)L] R_a(T) \quad (1)$$

In area of optical fiber L, the number of stokes scattering photon is as (2).

$$N_s = K_s S \nu_s{}^4 N_e \exp[-(a_0 + a_s)L] R_s(T) \quad (2)$$

In the area of optical fiber L, the number of Rayleigh scattering photon is as (3).

$$N_R = K_R S \nu_0{}^4 N_e \exp(-2a_0 L) \quad (3)$$

Where, N_e represents incoming light pulse photon number; K_R, K_a, K_s are the fiber Rayleigh, anti-stokes and the related coefficient of stokes scattering cross section, S represents the backscattering factor of the fiber; v_0、v_a、v_s represent he argument s Rayleigh, anti stokes respectively and stokes scattering light frequency; a_0、a_a、a_s are the Rayleigh, anti stokes rand stokes scattered light in the optical fiber transmission loss espectively; L is the fiber under test area of the incident to the distance; $R_a(T)$、$R_s(T)$ are the related coefficient for low energy and high energy level and fiber molecules on the layout, it is related to the temperature of the optical fiber area.

$$R_a(T) = [\exp(h\Delta\nu / kT) - 1]^{-1} \quad (4)$$

$$R_s(T) = [1 - \exp(-h\Delta\nu / kT)]^{-1} \quad (5)$$

Where $\Delta\nu$ represents Raman scattering light frequency; h is the Planck's constant; k is the boltzmann factor.

Temperature demodulation method is to use Stokes Raman scattering OTDR curve in demodulation anti stokes Raman scattering OTDR curve, through the type (1) and (2) the(6) can be obtained.

$$\frac{N_a(T)N_s(T_0)}{N_s(T)N_a(T_0)} = \frac{\exp(-h\Delta\nu/kT)}{\exp(-h\Delta\nu/kT_0)} \tag{6}$$

Through the type (6), we can obtain the (7):

$$\frac{1}{T} = \frac{1}{T_0} - \frac{k}{h\Delta\nu}\ln\frac{N_a(T)N_s(T_0)}{N_s(T)N_a(T_0)} \tag{7}$$

Where the Type T_0, $N_a(T_0)$, $N_s(T_0)$, $N_a(T)$, $N_s(T)$ are known, so the temperature T of the area can be obtained [3].

3.2. System Structure

Distributed optical fiber temperature measuring system structure is as shown in Figure 2, they are mainly composed of optical part and signal acquisition and processing parts. Optical parts are composed of semiconductor laser, optical fiber directional coupler, and other components of the sensing optical fiber, optical spectral components. The signal processing part is composed of photoelectric receiver and data acquisition processing computer [5-7].

3.3. Test Method and the Sensing Optical Fiber Structure

Only when the fluid supplying to the freezer is stopped, the longitudinal temperature can measure the actual frozen wall temperature, and it should be restored immediately after the completion of the testing, so the freezer longitudinal temperature measurement is a way of motor testing. In the vertical temperature freezer, the fiber optic should be worked according to, the three steps, the put down, detection and recovery.

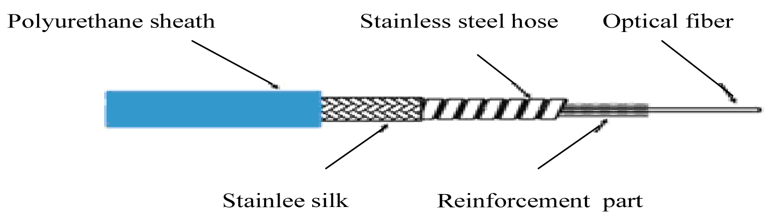

Figure 3. Structure of Armored Cable

Depth range of temperature measuring is from 0 to 673m (the counterweight tub is at 5 m point at the bottom), the optical fiber cable length in the temperature measurement is 800m. Due to the optical cable need to constantly down, recycling, so cable should have certain tensile ability, and guarantee it have enough tension and the accuracy of measurement. The design temperature measuring optical cable structure is as shown in Figure 3. The parameters of fiber parameters are as follows: multimode fiber core, 62.5 + 2.5 microns in diameter, the maximum attenuation is 3.5dB/km (850nm), 1.5dB/km (1300nm), working temperature is 50℃ ~ + 90℃, allowed bending radius is 10d (dynamic), 20d (static), allowed pull are 200N, 300N (long-term) of (short-term), long-term stress is 3000N/100mm, short-term stress is 5000N/100mm, weight is 25kg/km.

4. Longitudinal Temperature Detection

4.1. Detection Data Thermometer Hole

During a total of seven thermometer hole design, from C1 and C2 and C4, C5, C7 thermometer hole measured original geothermal abnormal in 530 meters to 580 meters, such as C1, 540 meters layer temperature of 42.6℃, compared to the main shaft and wind well provided a 10-13℃. After analysis because of formation damage, poured cement slurry, cement solidification of hydration heat, concrete situation as shown in Figure 4.

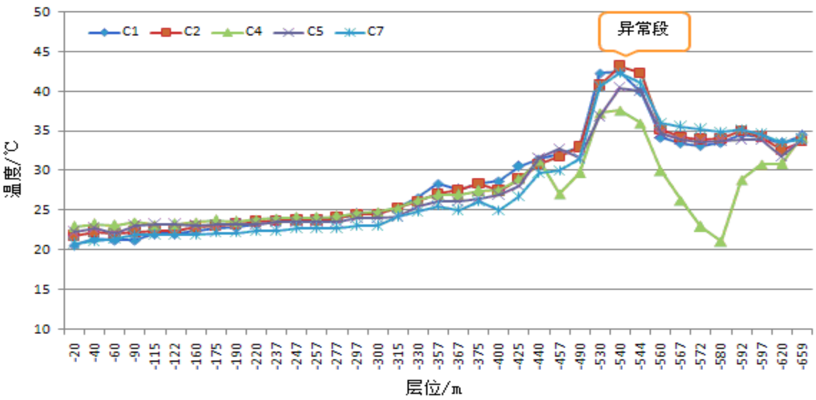

Figure 4. Curves of Auxiliary Shaft Original Ground Temperature

C1 ~ C7 thermometer hole temperature data in November 11, 2011 is as shown in Figure 5, in each layer of C1, the temperature distribution is between 6℃ and -17℃; in each layer of C2 temperature distribution is between -17℃ and 27℃; in each layer of C3 temperature distribution is between -24℃ and -26℃; in each layer of C4 temperature distribution is between 12℃ and -29 ℃; in each layer of C5 temperature distribution is between -12 and -26℃; A temperature distribution of each layers of C6 is between -25℃ and -28℃; A temperature distribution in each layer of C7 is between -3℃ and -23℃. The temperature range of the seven measuring point hole, which is about 0.1℃.

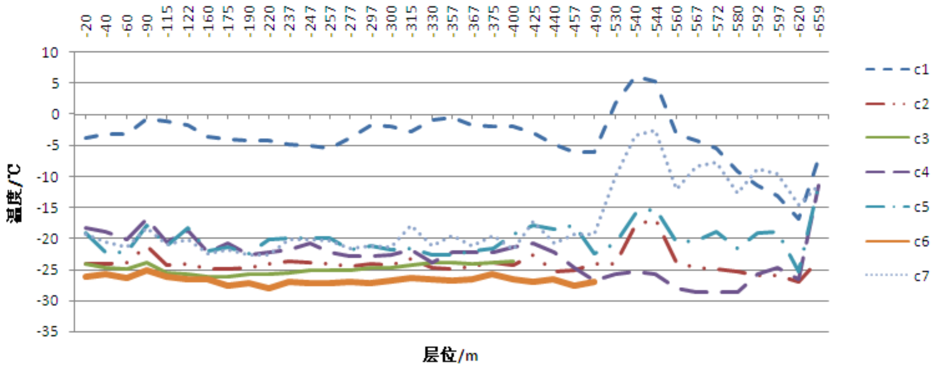

Figure 5. Curves of Thermometer Hole Temperature

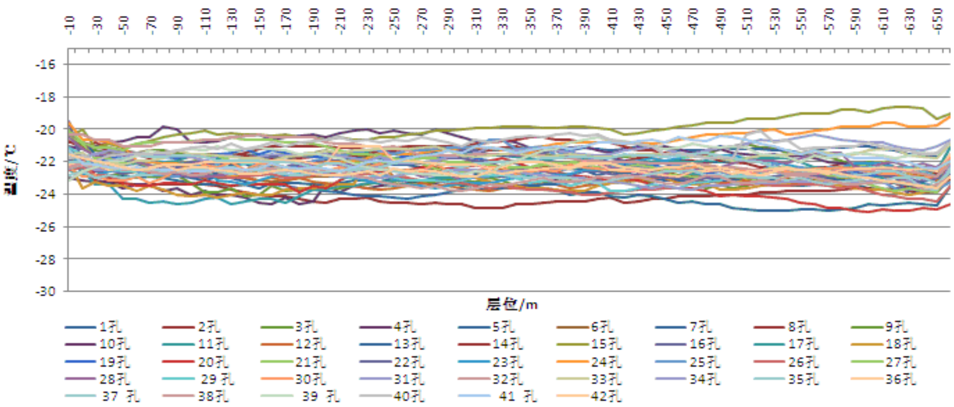

Figure 6. Curves of Auxiliary Shaft Outer Freezer Longitudinal Temperature

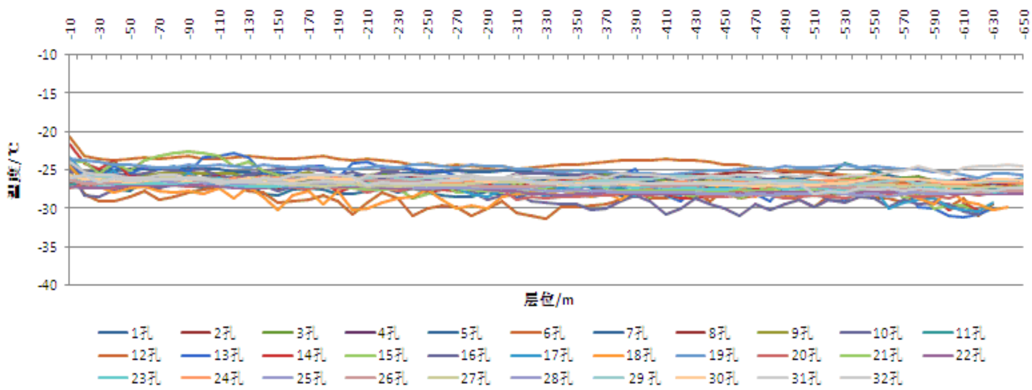

Figure 7. Curves of Auxiliary Shaft Inner Freezer Longitudinal Temperature

The Figure 6 and Figure 7 are the longitudinal temperature curve of 42 inner rows of 32 inner holes on November 8 to 12, 2011, the overall temperature distribution is between -19℃ and -30℃, from the analysis of figure , it can be found that freeze hole is running normally, and it has no plugging holes and short-circuit phenomenon, the longitudinal temperature declines with the increase of the depth of flat, and the exhaust temperature of freezer is lower than the temperature of the freezer unavoidably, and it is conformed to the freezing cycle law.

5. Conclusion

With the deepen of frozen depth and the application of some special occasions, Now the freezing method is facing a series of problems to be solved, the traditional detection method can not meet the needs of the development of technology. Freezing method has been relatively mature, but in the field of monitoring and automatic control, there exists many defects. Distributed optical fiber temperature measurement technology has been applied in some other fields, and related products is increasingly mature, the characteristics of distributed detection is especially suitable for freezing temperature field monitoring of the project, through the longitudinal temperature detection of freezer, we can be more intuitive grasp the development of frozen tube wall, and with the reduce of the equipment cost, the distributed optical fiber temperature measurement technology in the application of freezing engineering will be more and more widely.

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