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Feng Zhu, Gonghua Wang, Tongyu Liu, Gang Ma, Kenneth T. V. Grattan, Huimin Zhang, Jianwei Fu, Xiangnan Liu, Binxin Hu, Yuanzhen Li, "Optical fiber sensors for coal mine shaft integrity and equipment condition monitoring," Proc. SPIE 11340, AOPC 2019: Optical Fiber Sensors and Communication, 113401Y (18 December 2019); doi: 10.1117/12.2548154

SPIE.

Event: Applied Optics and Photonics China (AOPC2019), 2019, Beijing, China

Optical Fiber Sensors for Coal Mine Shaft Integrity and Equipment Condition Monitoring

Feng Zhu*[a], Gonghua Wang[b], Tongyu Liu[a,c], Gang Ma[b], Kenneth T. V. Grattan[a,e], Huimin Zhang[d], Jianwei Fu[d], Xiangnan Liu[d], Binxin Hu[a],Yuanzhen Li[d]

[a]Laser Research Institute, Qilu University of Technology (Shandong Academy of Sciences), Jinan, 250014, China; [b]Yanzhou Coal Mining Ordos Energy Company Limited, Ordos, 017020, China; [c]Shandong Micro-Sensor Photonics Limited, Jinan, 250103, China; [d]Ordos Yingpanhao Coal Co., Ltd. Ordos, 017300, China; [e]School of Mathematics, Computer Science & Engineering, City University of London, London, EC1V 0HB, United Kingdom

ABSTRACT

Shaft is an important structure of mine. Deep mining increases mine pressure, induces shaft deformation and affects mine normal lifting. How to improve the inspection efficiency, reduce the maintenance cost and ensure the normal operation of the shaft is an important problem facing the mine. The paper introduces the optical fiber sensing technology to monitor the equipment status of the main shaft, puts forward the implementation scheme of the optical fiber monitoring of shaft deformation, and sets up a shaft equipment condition monitoring system based on the optical fiber sensing technology. It can realize equipment displacement monitoring, strain monitoring and vibration signal monitoring in the process of shaft operation. Comprehensive on-line monitoring of shaft running state can be realized, which opens up a new method for shaft deformation monitoring technology. Fiber optic sensing monitoring technology is of great significance to the safe operation of shaft.

Keywords: optical fiber sensors, shaft equipment condition monitoring, vibration signal, stress and strain, displacement

1. INTRODUCTION

As an important part of coal mine, mine shaft is a throat project to promote the transportation of coal (or gangue), transport personnel, materials and equipment, as well as throat works for ventilation and drainage.In the progress of mine production, the safe operation of shaft equipment is the premise of the normal production and operation of the mine, and it determines the economic benefit of the whole mine.

Since the 1980s, more than 100 shaft walls in Huainan, Huaibei, Datun, Xuzhou, Yanzhou, Jining and other mining areas in eastern China have been damaged to varying degrees, and the coal mines have great economic loss[1]. In the process of skip or cage lifting operation, due to the influence of geological conditions and mining factors, some deformation occurs in the shaft, the longitudinal bending deformation of the shaft cage guide affects the promotion, and even causes the jam accident, lateral fracture of the shaft wall, spalling of concrete in the fracture zone, bending of the longitudinal steel bar in the shaft wall to the shaft, which seriously affect the normal production of the mine.

On 5 August 2010, the shaft wall of the copper-gold mine in San Jose, northern Chile, was broken and a serious collapse occurred, causing 33 miners to be trapped 700 meters underground. After a long,69-day rescue, the trapped miners were finally rescued. In 2014, dozens of miners were trapped in an illegal mine in northern Mozambique due to inadequate safety measures and lack of monitoring. On December 25,2015, a coal mine in Pingyi City was caused by the collapse of the mined-out area of the adjacent abandoned coal mine, and the shaft wall of the No.4 lifting shaft collapsed and the 14 staff were trapped in the shaft[2].

By the end of 2017, 4980 coal mines were announced to be produced and constructed nationwide. The number of non-coal mines is about 30000. Most of the mines were equipped with shaft lifting and transportation devices, which faced problems such as shaft safety monitoring and protection[3]. In recent decades, many scientific researchers and field experts have accumulated a lot of control experience[4-9], but a series of critical theory and technical problems have not

*feng.zhu@sdlaser.cn

AOPC 2019: Optical Fiber Sensors and Communication, edited by Jie Zhang, Songnian Fu, Jun Yang, Proc. of SPIE Vol. 11340, 113401Y · © 2019 SPIE
CCC code: 0277-786X/19/$21 · doi: 10.1117/12.2548154

yet been formed, and the mechanism of shaft failure is still controversial and belongs to the interaction between the multi-effect factors. At present, most scholars believe that the thicker the depth of the shaft is, the thicker the thickness of the topsoil layer is, the greater the possibility of damage to the shaft. The consolidation settlement of topsoil alluvium acts as a huge vertical additional force on the shaft lining, which leads to the phenomenon of vertical stress concentration in the shaft lining, which is the main cause of shaft failure, and puts forward many effective repair methods and measures. However, due to the long service life of the shaft and the long-term underground complex environment, even the repaired shaft is at risk of being destroyed again. Therefore, it is particularly important to adopt effective monitoring means to evaluate and track the safety state of shaft structure.

2. GENERAL SITUATION OF SHAFT

Taking a coal mine in China as an example, three shafts have been drilled. The diameters of main shaft, auxiliary shaft, return air shaft are respectively Φ 9.4m, Φ10m and Φ7.5m. the design depth of shaft is respectively 849.5m, 789.5m and 757.0m. The shaft passes through deep water-rich Cretaceous and Jurassic strata. The formation lithology is sandstone and conglomerate rock mass, all of which are argillaceous or sandy argillaceous cementation. The degree of cement is loose, and the shaft wall is prone to local problems.

The lifting system of the main shaft consists of four skips, the size of which is 3.7m × 1.5m × 19m. Each skip is equipped with symmetrical two groups of cage guide to maintain the stability of skip lifting. The cage guide is fixed on the bunton, the length of each cage guide is 8 m, the bunton is set up every 4 m, and the cage guide and bunton are fixed on the shaft wall, which is shown in figure 1.

During the lifting operation of the skip, due to the factors such as topsoil settlement, temperature rise, ground pressure and self gravity, certain deformation of the shaft, squeezing the bunton, eventually resulting in deformation, dislocation and even falling off of the cage guide, seriously affecting the normal operation of the skip and the life safety of the staff.

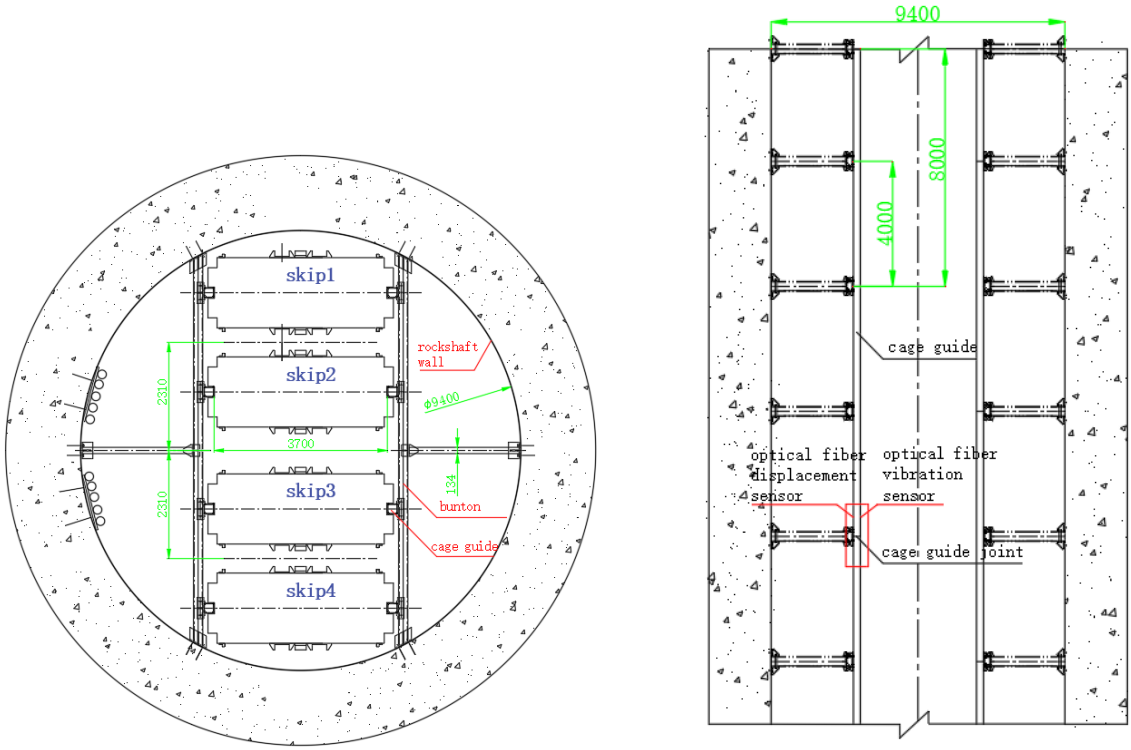


Figure 1. Main shaft structure diagram

3. OPTICAL FIBER SENSING SHAFT EQUIPMENT CONDITION MONITORING SYSTEM

3.1 Advantages of optical fiber sensing technology

At present, there are many problems in the main monitoring methods of shaft deformation and failure at home and abroad, such as complex monitoring system, low monitoring accuracy, easy to be disturbed by the environment, short life, low stability and so on. Therefore, it is necessary to find an advanced and scientific monitoring method to monitor and warn shaft deformation and failure for a long time. Optical fiber sensing technology can meet the above shortcomings and has good applicability.

Fiber grating sensor is a kind of sensing technology which is made of optical fiber in the late 1970s and uses light as information carrier. Compared with traditional electronic sensors, they have the following unique advantages:

(1)The light as the sensing signal is basically not interfered by the external electromagnetic field, and the long-term drift is small, so it can be used for long-term and reliable continuous on-line detection.

(2)Inherently safe, uncharged, long signal transmission distance, up to 10 km.

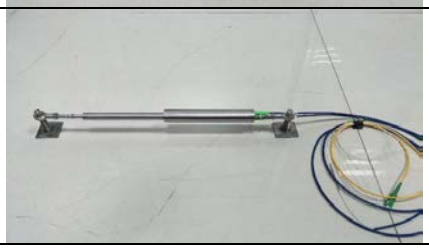
(3)The reuse ability is strong, and it can realize the continuous monitoring of multi-point, two-dimensional lattice or spatial distribution, which is especially suitable for monitoring the safety state of monitoring targets with a wide range of space.

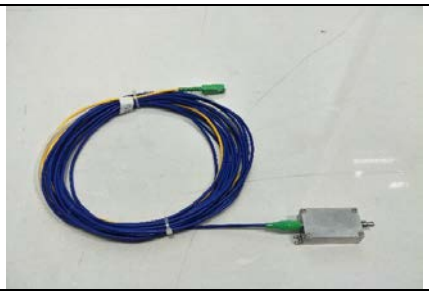
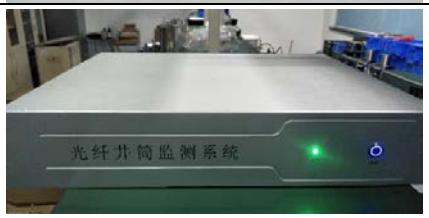
3.2 System layout

(1) system structure

The shaft safety monitoring system based on optical fiber sensing technology can realize the comprehensive long-term on-line monitoring of shaft operation status, which is of great significance to the safe operation of the shaft. The monitoring contents and equipment of the optical fiber sensing shaft equipment status monitoring system are shown in Table 1. It is mainly used to monitor and analyze the deformation of bunton, cage guide displacement, cage guide vibration/sound information and tail rope status. The monitoring and analysis are carried out by using fiber grating strain gauge, fiber grating surface crack meter, fiber acceleration sensor(fiber vibration sensor), fiber grating high-speed demodulator and self-developed monitoring software.

Table 1. Shaft equipment condition monitoring

No.	Monitoring content	Sensors/ equipment	Installation site	Physical drawing
1	Bunton strain deformation	Fiber Bragg Grating Strain Gauge	The bottom and back of the bunton	
2	Cage guide displacement monitoring	Fiber Bragg Grating Crack Meter	The back of cage guide, the joint and expansion joint of cage guide	

3	Cage guide vibration monitoring	Optical Fiber Vibration Sensor	The back of cage guide	
4	Data acquisition system	Fiber bragg grating high speed, demodulator, data acquisition Software	Complete sensors data collection, analysis, early warning, alarm, saving and viewing.	

(2)Location and quantity of sensors installed

Considering that the monitoring response distance of the optical fiber vibration sensor is about 100 m, according to the characteristics of the sensor and the special position of the shaft, the installation number of the optical fiber vibration sensor is 8, two fiber grating strain gauges are arranged on each button, and one fiber grating crack meter is arranged at the joint of the cage guide. The position and quantity of the sensors are shown in table 2, figure2. The monitoring software is shown in figure 3.

Table 2. Sensor installation position and number

No.	location	Quantity / Branch			Number of prefabricated optical cable joint cores	Remarks
		Optical Fiber Strain Gauge	Optical Fiber Crack Meter	Optical Fiber Vibration Sensor		
1	level -74	-	2	-	2	Cage guide expansion joint
2	level -300	4	2	2	2	Normal area
3	level -440	4	2	-	2	Rockshaft variable cross-section
4	level -540	4	2	2	2	Rock formation weakness plane
5	level -630	4	2	2	2	Aquiclude
6	level -650	-	2	-	2	Cage guide expansion joint
7	level -740	4	-	2	2	Underground chamber junction
8	level -790	4	2	-	2	Underground chamber junction
Total		24	14	8	16	

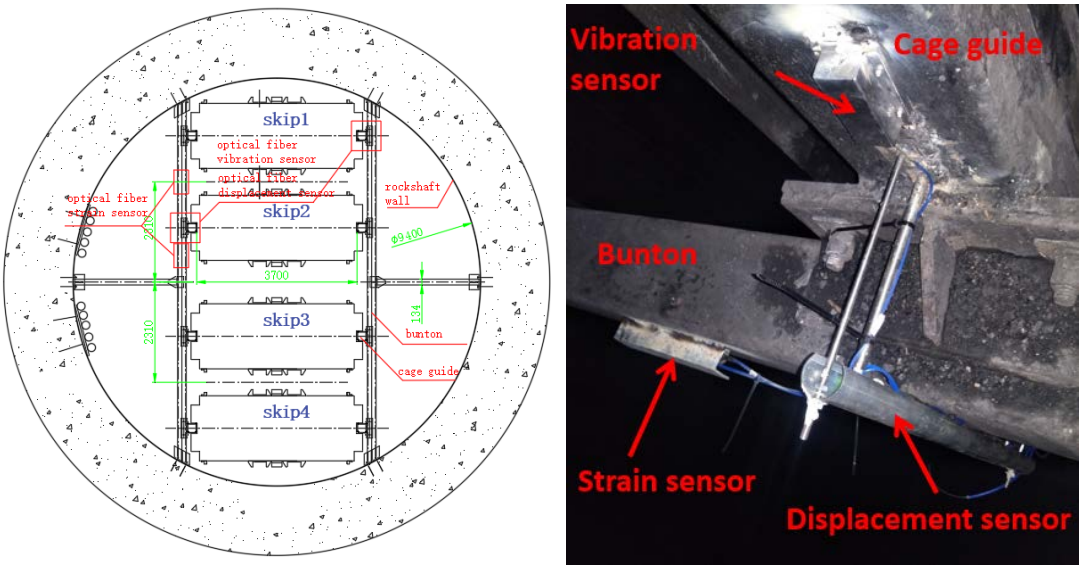


Figure 2. Installation diagram of optical fiber sensor

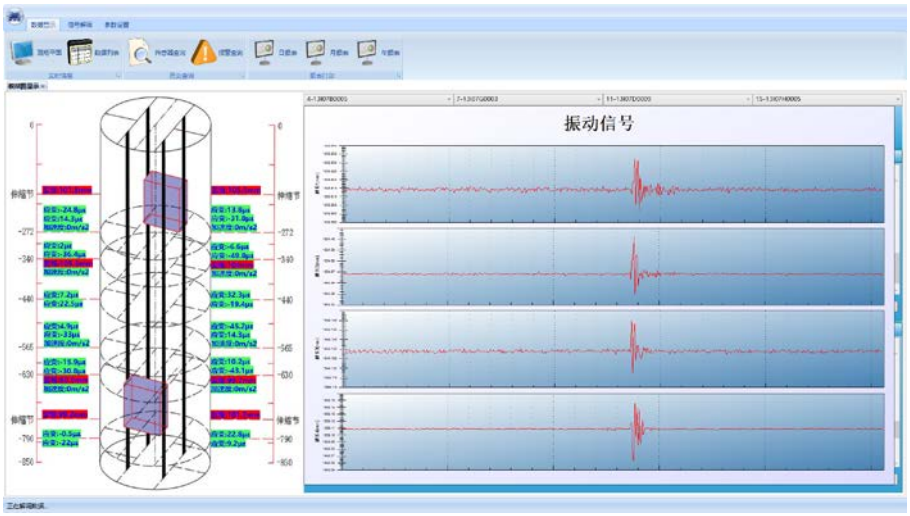


Figure 3. Shaft monitoring software

4. CONCLUSION

(1)Optical fiber sensing technology is suitable for application in mine shaft because of its advantages, such as not disturbed by external electromagnetic field, essentially safe and uncharged, long signal transmission distance and strong replication ability, which provides a new technology and method for equipment condition monitoring in deep mine.

(2)The optical fiber sensing shaft safety monitoring system is based on fiber grating crack gauge, fiber grating strain gauge, optical fiber vibration sensor and other sensors, equipped with fiber grating high speed demodulation instrument, through on-line monitoring software, realized the acquisition, analysis, early warning and alarm of shaft operation data, which provides a guarantee for mine shaft safety.

ACKNOWLEDGMENTS

This work was partly supported by the Key Research and Development Plan of Shandong Province (No. 2018GSF120008) and the Ph.D. Foundation of Natural Science Foundation of Shandong Province (No. ZR2019BEE019).

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