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A new convergence monitoring system for tunnel or drift based on draw-wire displacement sensors

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ABSTRACT

Convergence monitoring of the drift or tunnel in construction and running stage is essential, especially in the case of frequent human interferential activities. It is useful to monitor the convergence for engineering workers to prevent collapse caused by excessive settlement. This paper introduces a continuous cross-section monitoring system which used control circular board, tilt sensor and draw-wire displacement sensor as data acquisition device. The convergence monitoring system, which can realize continuous monitoring, easy installation, no artificial attendant, no security vulnerabilities, and no interference to normal running of the tunnel or drift, can satisfy the measuring requirement of tunnel or drift because of its any measuring frequency, little measuring error, and high accuracy that reaches 0.01 mm. The using experience of the monitoring system in a gold mine in Shandong province verified that it is good at monitoring the deformation of the cross-section.

1. Introduction

With the rapid development of subway, tunnel, mine, as well as increased awareness of construction engineering safety, the construction safety problems of subway, tunnel, drift, especially how to ensure the engineering safety and running efficiently has become the social extensive concern (Oreste, 2011; Kaiser, 1993). A continuous monitoring is necessary to avoid the instability and unexpected caving (Chung et al., 2006; Peila et al., 2004). The convergence monitoring of cross-section, which is subject high attention of engineering workers, has been essential monitoring items in the whole life cycle of tunnel or drift, especially in the environment with frequent interferential activities around (Kontogianni and Stiros, 2005; Mezger et al., 2013). It is the important method for the engineering workers to check their design and ensure the safety of construction and running (González-Nicieza et al., 2008; Kontogianni and Stiros, 2002). Recently, the techniques used in engineering can be divided into three categories, which are automatic tracking total station observation technology, digital close-range photogrammetry, and point directly measuring technique (Hu et al., 2014; Lato and Diederichs, 2014; Oreste, 2013; Fekete and Diederichs, 2013; Van Gosliga et al., 2006).

Automatic tracking total station observation technology, which used in Shanghai No. 2 subway, Brussels tunnel engineering to monitor the cross-section, has been verified in tunnel construction. The advantages of automatic tracking total station observation technology are high measuring accuracy and low light requirement. However, the environment of the tunnel or drift cannot satisfy the requirement of the dust for the automatic tracking total station. Additionally, the monitoring equipment is too expensive to install in all length of drift or tunnel. The advantage of the digital close-range photogrammetry technology, which is low environmental requirement, is that it can use hand-held camera or high precision camera to collect deformation data of the cross-section (Mezger et al., 2013). The disadvantage of it is that it cannot work when the light is not enough in the tunnel or no secondary light source. Auxiliary light, of which lighting quality has great influence on measurement accuracy and stability of the monitoring system, should provide in the monitoring process. Meanwhile, a large number of auxiliary points should be placed to offer assistant for image recognition location after photographing. Point directly measuring technology used relative displacement and rotation of the equipment individual parts which installed directly on the cross-section of the tunnel to calculate the deformation of the cross-section. As the representative equipment of the point directly measuring technology, traditional convergence, Bassett convergence, are bad at monitoring the displacement of any cross-section.

The convergence monitoring effect of tunnel or drift is closely related to the measuring precision and frequency. Low precision and frequency would lead to no observed deformation, time delay. Too high precision and frequency would result in low work efficiency, unnecessary high costs. The usual measuring methods

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used for convergence monitoring of tunnels and drifts need to interrupt the traffic, especially when the tunnels and drifts are working. It is not applicable for the measuring method to monitor deformation of tunnel and drift which reach a length of several kilometers or more than a dozen kilometers.

Considering disadvantages of the traditional convergence monitoring appliance, a new convergence monitoring system, which was one of point directly measuring technology and based on draw-wire displacement sensor, was developed to monitoring the deformation continuously (Atul et al., 2010). Fortunately, the layout of the cross-section according to detailed geological data obtained by geological drilling before construction can make up deficiency of the point directly measuring technology. The monitoring system is easy to install to realize automatic measurement with little measurement error. Meanwhile, the monitoring has no interference on the transportation.

2. Convergence monitoring system constitution

The convergence monitoring system, which is shown in Fig. 1, consists of data acquisition device, data transmission and storage device. Data acquisition device, which is monitoring the deformation of cross-section, are composed of two measuring boxes, four groups of protective casing, three fixed bases and four tilt sensors. Measuring box is an nbc protection shell which is equipped with transformer, control circular board and two draw-wire displacement sensors. The draw wire of draw-wire displacement sensors connects to inside protective casing pass through the hole on the nbc protection shell and outside protective casing. One end of the inside protective casing which is connected to the draw wire is placed in the outside protective casing, the other end is fixed on the fixed base with hinge joint. The transformer in the nbc protection shell connects to the power supply circuit to supply the power for the measuring box. Meanwhile, the tilt sensors collect angles variation of each group protective casing. One computer can be placed near the cross-section to storage the monitoring data if conditions allowed. The data analyst can copy or analyze the data through the internet remote operation.

3. Testing principle

The draw wire is drived a movement by the inside protective casing when a slip generates between the inside protective casing and outside protective casing. The output direct proportion signal is realized by synchronous rotation of transmission mechanism and encoder. The tension keeps the same value when the draw wire moves. The draw wire stretches when the relative distance between point *D* and *E* increases likely the No. 1 slip shown in Fig. 2. Otherwise, the draw wire gets shorter and the No. 2 slip occur. The inside protective casing is a seamless stainless steel tube with 8 mm of its inner diameter, 10 mm of its external diameter, 1 mm of wall thickness, and the outside protective casing is a seamless stainless steel tube with 10.7 mm of its inner diameter, 12.7 mm of its external diameter, 1 mm of wall thickness. In order to reduce the relative sliding friction, the surfaces of inside protective casing and outside protective casing take the polishing processing. Additionally, the length of the protective casing can change according to the size of cross-section. And tilt sensors collected the angles variation in all the monitoring process.

The number of the square wave A and B, which generated by encoder according to the changed length of the draw wire, can used to calculate displacement of the two points. The phase difference which is 90° between the square wave A and B can be used in the direction recognition of the pulse as shown in Fig. 3. Discerning direction hardware circuit distinguishes the state of phase A at the signal increased time of phase B. When the state of phase A is high level, the encoder is a positive running, which would lead to the reversible counter take add pulse operation at the next signal

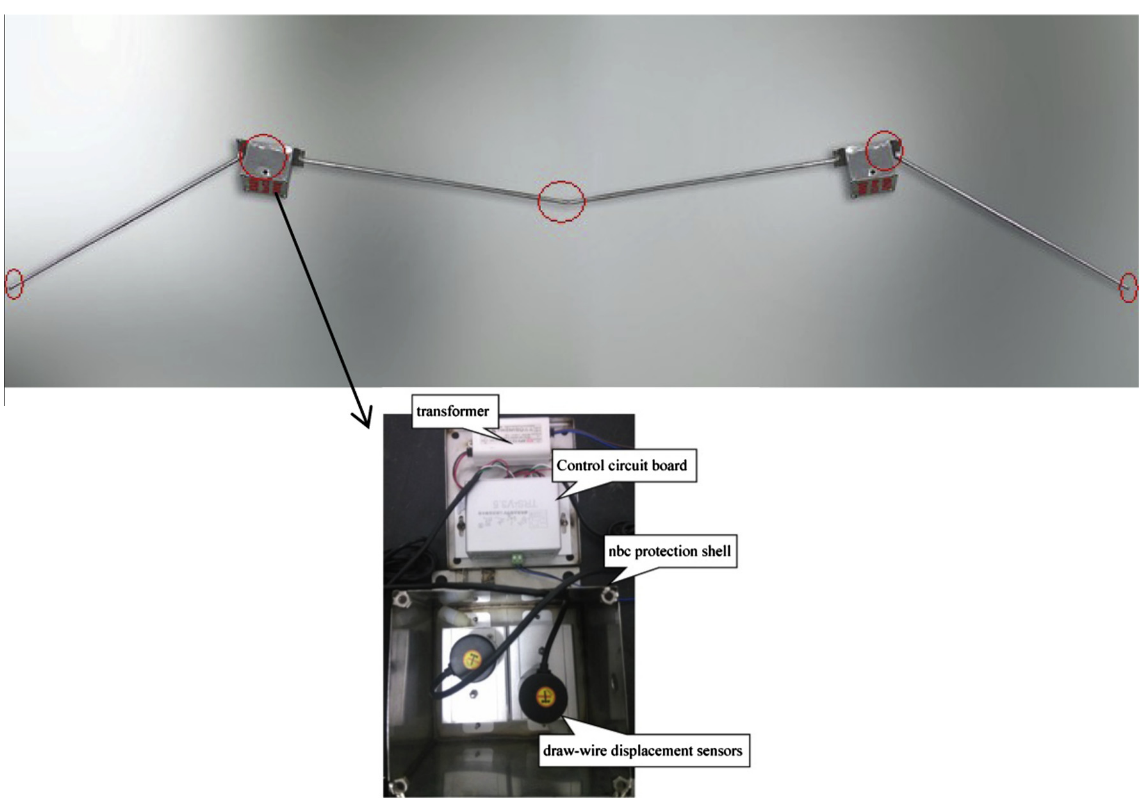

Fig. 1. Convergence monitoring system constitution.