Design and Application of Automatic Monitoring System based on Static Force Level in Construction of Shield-bored Underneath Metro

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Abstract. When metro shield passes through existing operating lines, it is necessary to carry out automatic monitoring of existing lines. In this paper, taking the construction of Changsha Metro Line 4 under the shield of the existing Metro Line 2 as an example, the static level is set up in the construction affected area to monitor the vertical displacement of the track bed automatically. According to the actual situation of the site, a complete set of automatic monitoring system is designed, and a detailed site implementation scheme is formulated. Finally, the deformation data is analysed, and the characteristics of the whole system are summarized.

1. Introduction
With the development of the economy and the accelerating process of urbanization, Changsha has been vigorously building subway tunnels in recent years. Due to its many advantages, the shield method has gradually become the preferred method for the construction of urban underground tunnels. During the construction of the subway, the shield machine passing through the existing building often occurs. How to reduce the disturbance of construction to the ground and ensure the safety of existing buildings is one of the urgent problems to be solved in subway construction. Monitoring plays an important role in the construction of the subway. Through monitoring, the actual effect of the construction method and the impact of the construction on the surrounding environment could be understood. According to the monitoring data, the relevant personnel could timely and accurately forecast the potential safety hazards or accidents, and adjust the construction parameters to take appropriate engineering measures.

This paper designs and develops an automatic monitoring system based on static force level. The whole system can automatically collect the deformation data of field structure, upload the data to server database in real time. At the same time, using mobile interconnection technology, relevant personnel can view the data in real time through computers, tablet pcs and mobile phones, and generate data reports. At the same time, the application of the whole system in Changsha Metro Line 4 shield tunnel crossing the existing operating line is introduced.

2. The Design of Automated Monitoring System

2.1. The design of hardware system
The whole monitoring system consists of data collection unit and server unit and monitoring terminal unit [1,2]. The three units are connected by a data communication module using 4G communication.
technology. The data collection unit transmits the settlement data collected by the static level to the monitoring server through the 4G module. The relevant personnel of the project can also view the field data and real-time understand the settlement information at any time and any place through the networked client computers, tablet pcs, mobile phones and other terminals installed with monitoring system. At the same time, the project management personnel can set various monitoring parameters through software operation, flexibly adjust the automatic monitoring frequency, set early warning, alarm value, etc. The Composition block diagram of the automatic monitoring system is shown in Fig. 1 below. Field installation of automatic monitoring system is shown in Fig.2 below.
2.2. The design of sensor system

The static level is mostly liquid level type, and the change of water level is measured by capacitance, inductance, magnetostriction and other sensors. The sensor system needs a large volume of liquid storage tank, and the installation of the instrument needs to be levelled, so it is easy to be affected by the atmosphere and the site, and the measurement accuracy is difficult to guarantee. The monitoring system adopts a new type of hydraulic static level, which calculates the change of liquid level by measuring the liquid pressure with the diffusion silicon core sensor. The sensor has the characteristics of small volume, high precision and convenient installation. To monitor the settlement or uplift of the track bed, the static level needs to be installed on the track bed. According to the height difference of measuring points and the range of settlement change in the monitoring area, select a sensor with a range of 1.5m, and its communication interface is RS485. See the table below for specific parameters.

Table 1. Parameter table of static force level.

| Project                 | Parameter          |
|-------------------------|--------------------|
| Range                   | 0-1500mm H2O      |
| Accuracy                | 0.2mm              |
| Resolution ratio        | 0.01mm             |
| Annual stability        | 0.5mm              |
| Output signal           | RS485              |
| Supply voltage          | 7-12V DC           |
| Operating temperature range | -20–85℃        |
| Temperature compensation range | 0–60℃        |
| Overload capacity       | 150%               |
| Degree of protection    | IP67               |

The whole sensing system includes liquid storage tank, water, liquid pipe, vent pipe and static level sensor. The system is suitable for measuring the relative settlement of multiple points, and the sensing system is shown in Figure 3 below. When in use, the datum static level is installed in a stable position far away from the settlement area, and the measuring points of each static level are connected by liquid pipe and vent pipe. After installation, first collect a group of initial pressure values. In the process of monitoring, when the elevation of measuring point and reference point changes, the measured pressure will also change, and the settlement of each measuring point can be calculated [3]. The calculation formula is as follows.
\( \Delta h = \frac{(P_i - P_j) - (P_{i0} - P_{j0})}{\rho g} \)

In the formula, \( \Delta h \) is the settlement, \( P_i \) is the measured value of the measuring point, \( P_{i0} \) is the initial value of the measuring point, \( P_j \) is the measured value of the reference point, \( P_{j0} \) is the initial value of the reference point, \( \rho \) is the density of the liquid, \( g \) is the acceleration of gravity.

2.3. The design of software

The whole software is developed in the integrated development environment of visual studio 2015. Software adoption vb.net Development language, using SQL sever2008 database. The software supports multi project, multi-user, hierarchical authority management and other operations, and has system configuration, data display, report generation, early warning and alarm functions.

3. Engineering Application

3.1. General situation of engineering

In the section between Yingwanzhen and Hunan Normal University of Changsha Metro Line 4, the shield machine will run through the existing Metro Line 2 shortly after its start. During the construction of the project, the deformation of the tunnel in the affected area is monitored, and the influence of shield tunnelling on the tunnel is analysed, so that effective measures can be taken in time to control the deformation of the existing line and protect the safe operation of Line 2.

3.2. Measuring point arrangement and field installation

According to the location plan of new and existing metro tunnels, the monitoring range of line 2 tunnel is determined to be 50m. There are 11 monitoring sections in line 2, each section is arranged with one measuring point on both sides of the track bed. The datum point is arranged at a stable position outside the construction impact area. There are 22 measuring points and 1 datum point in each tunnel. The layout of measuring points is shown in Figure 4.
The field installation is divided into the following steps: 1) sensor installation and fixation. Fix the sensor in the pre-planned position with the expansion screw. 2) installation and fixation of liquid storage tank. The expansion screw is also used to fix the liquid storage tank at the pre-planned position of the arch waist. It should be noted that the height difference between the lowest point of the sensor and the liquid level of the liquid storage tank cannot exceed the range of the sensor. 3) connection of lines. The RS485 signal interface and power interface of the sensor adopt 4-core fast waterproof connector. The cable length is determined according to the distance between the sensors, and the field is connected quickly. Finally, the bus is introduced into the acquisition box. 4) reservoir, vent connection. The sensor storage tanks are connected by a transparent Pu pipe, and finally connected to the bottom of a storage tank. At the same time, to eliminate the influence of atmospheric pressure, all sensors share a common vent pipe, and finally connect to the side of the reservoir, forming a closed air pressure self-balancing system. In order to reduce the bubbles in the water, the boiled pure water is usually selected. When filling water, pay attention to check whether there are bubbles at the connection between the sensor and the liquid pipeline, and gently vibrate to drain the bubbles, so as to ensure that the bubbles in the whole water path are drained [3].

3.3. Data verification and analysis
In order to verify the accuracy and stability of the system, after the system is installed, the initial values of the measuring points are measured manually by total station. After a period of construction, through comparing the data of automation and manual measurement at the same time, it can be seen that the two groups of measurement data are consistent, the data deviation is less than 0.5mm, and the data of the right line are compared. As shown in Figure 5 below.

Through the automatic monitoring data, it is found that the relatively stable fluctuation of the data is usually about 0.1mm during the subway outage. Because the sensor is installed on the track bed, the subway is easily affected by the train during operation, and the monitoring data fluctuate greatly. In order to solve this problem, according to the train operation schedule, set the monitoring frequency by software to stagger the train running time [4], or reduce the impact of train running by software filtering [5].

4. Conclusion
This paper introduces the design and application of the automatic monitoring system based on the static level in the subway shield crossing the existing line. Through the field installation and
application, the real-time monitoring of the roadbed settlement is realized all day. It provides real-time data for MJS grouting reinforcement construction in the early stage, guides the adjustment of parameters for the shield tunnelling construction, and ensures the safe operation of existing metro lines.

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