Design and test of slope monitoring digital inclinometer

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Abstract. According to the functional requirements of the slope monitoring system, the angle sensor is taken as the research object, and the digital inclinometer suitable for slope monitoring is developed. The software and hardware design, data error correction, data transmission protocol and external structure design of the inclinometer are mainly solved. At the same time, the joint adjustment, installation and operation and maintenance of the slope monitoring system are completed.

1. Introduction
Geological disasters caused by slope engineering generally undergo a process from gradual change to abrupt change, and some precursors are generated before the geological structure is destroyed. However, due to the complicated influencing factors, the mechanical parameters and structural properties of the slope soil vary from place to place, and the slope state is a process of change, which is difficult to determine based on human intuition and experience. Monitoring is an important means of slope stability evaluation method, and the objective law of slope deformation process can be reflected by quantitative data. The development of modern science and technology has led to continuous innovation in the field of slope monitoring, and the accuracy and reliability of various monitoring technologies have also been greatly improved.

China began its research work on slope monitoring after 1970, and it started relatively late. The initial monitoring methods were used less, and most of them were imported monitoring technologies. In the 1980s, Xie Shouyi and other examples of landslides in the Three Gorges reservoir area were analyzed. The typical thresholds of rainfall landslides were designed by comparing different types of rainfall, and the probability of rainfall induced by typical landslides was calculated according to the theory of extreme value distribution. Statistical analysis.

In summary, because the influencing factors, scales and types of geological disasters are different, there are many contents and methods for monitoring and forecasting slopes, and their advantages, disadvantages and scope of application are also different. According to the geological conditions of the slope in a specific environment, the monitoring method suitable for the actual project is determined. Through the reasonable design of the slope monitoring system, the monitoring and monitoring data can be analyzed and processed, and the stability state of the slope engineering can be accurately and timely
verified. Sexual evaluation, to achieve the purpose of monitoring and early warning, effective control [1, 2].

2. Geotechnical principles of slope monitoring

For the safety evaluation of slopes, the primary problem is to analyze the causes of slope instability. The key point of analyzing the instability of slopes is to study the instability mode of slopes. The research shows that the damage of slope stability is closely related to the type of soil structure that constitutes the slope [3]. According to the slope structure of the slope, the scholars generalize the deformation and damage of the slope into a variety of failure modes, the most common of which There are three types: the bedding slip failure mode, the slip tensile failure mode, and the crush failure mode, which are briefly introduced here.

①Stratum slip failure mode. Such landslide patterns typically occur in bedding slope structures with weak interlayers or inter-layer displacements. The main manifestation is that the rock mass undergoes a whole slippage along the weak interlayer between the soil layers. The reason for the damage is that the anti-sliding force provided by the weak interlayer is too small to resist the sliding force generated by the upper rock mass. The schematic diagram of the bedding slip failure mode is shown in Figure 1. AB faces empty, and the rock mass ABC slips along the slip surface AC. Another reason is that the shear strength of the weak interlayer becomes smaller, and the anti-sliding force is smaller than the rock mass. The sliding force of ABC caused the rock mass to slip and damage [4].

②Slip tensile failure mode. It usually occurs in hard rock soft rock, soft and hard interbed, thin layer soft rock bedding slope with large slope angle of excavation face. When the slope angle is larger than the gentle inclination or medium inclination of the inclination angle of the rock layer, such The landslide mode occurs. The reason for the decline is that after the slope excavation, the rock mass of the slope slides along the lower weak layer along the direction of its own gravity, and when the sliding force reaches the limit of the anti-sliding force of the landslide surface, The amount of displacement is increased to a certain extent, and the slip body is pulled by the cracker. The slippage cracking failure mode is shown in Figure 2. [14]

③Crush failure mode [5]. It mainly occurs in the steep dip angle soft and hard rock interbed and slate, shale, schist and mudstone bedding rock slopes. The rock mass where such damage occurs is generally a thin layer of flexible hard rock, which underlies a weak rock formation. When the slope of the slip surface of the slope is significantly larger than the comprehensive internal friction angle, the overlying rock mass has the condition of sliding. However, if the slip surface is not empty and the rock mass is blocked, it will cause longitudinal extrusion of the bedding rock plate near the foot of the slope, causing it to bend and deform, resulting in crushing and destruction. The schematic diagram of the crush failure mode is shown in Figure 3. [14]

![Figure 1. Straight slip failure mode](image1)
![Figure 2. Slippage failure mode](image2)
![Figure 3. Crush failure mode](image3)

3. Digital inclinometer design

The digital inclinometer equipment is located at the forefront of the slope monitoring system and is the basic part of the slope monitoring system. The acquisition of the angular deformation data is used to obtain the deformation data of the slope. This chapter focuses on the design of the inclinometer, from
six aspects of functional requirements, hardware design, software design, external structure design, data communication protocol, anti-interference design.

3.1. Functional requirements
An inclinometer is a device used to measure changes in the tilt angle of a monitoring point. In the slope monitoring system, the inclinometer is embedded in the borehole of the point to be measured to monitor the change in angle. Due to the particularity of its environment, it has decided to have unique functional requirements for angle sensors.

A. Real-time angle measurement: The application of the angle sensor in the slope monitoring system is mainly reflected in the real-time continuous monitoring of the change of the inclination angle of the internal geological structure of the slope monitoring point. Through the corresponding relationship between the angle change and the displacement, the displacement change of the monitoring point is calculated[6].

B. Low power consumption: The slope monitoring system uses battery-powered, solar-panel-charged power supply modes in the field, which determines the low-power characteristics of the angle sensors and nodes.

C. High precision and high sensitivity: The high-risk and strong destructive nature of landslide accidents determines that the slope monitoring system must accurately and reliably implement monitoring, which puts high demands on the accuracy and sensitivity of the angle sensor. If the inclinometer length is 1m, the deflection angle of 1 degree will result in a displacement of 17.45mm. Therefore, the accuracy should be controlled within the accuracy range of 0.01 degrees[7,8].

D. Abnormal detection and alarm: When the node or angle sensor has insufficient power supply voltage, data drift or other abnormal conditions, the node can detect and generate alarm information according to the situation and transmit it remotely, so that the background monitoring center can capture the abnormal information in real time and take corresponding measures.

E. Waterproof and anticorrosive performance: The slope monitoring system is installed in an open environment with abundant rainfall and frequent groundwater activities. Because it is a high-precision electronic device, it determines that its external structure needs to be sealed and has good waterproof and anti-corrosion performance.

F. Robustness: The complexity of the field environment requires that the angle sensor must have good robustness, the external structure is firm, the system performance is stable, and equipment damage or system disorder will not occur due to slight changes in geology or subtle changes in environmental factors.

3.2. Hardware design
According to the functional module distinction, the inclinometer is mainly composed of four parts, namely the microcontroller module, the sensor module, the serial communication module and the power module. The system composition is shown in Figure 4.

Microcontroller module design: The microcontroller module is the nerve center of the inclinometer device. The micro-single-chip computer controls the orderly operation of each component through the program; the angle sensor and the ADC module are the sensory organs of the inclinometer device, from
the micro angle. The sensor component realizes the acquisition of the deformation characteristic data of the slope; the communication module is the expression of the inclinometer device, and is a bridge for the communication between the inclinometer device and the external world, and transmits the state of the inclinometer device to the corresponding components of the slope monitoring system. Information; the power module is the source of energy for the inclinometer equipment, providing power to the inclinometer equipment.

Considering the functional requirements of the angle sensor, this topic selects the 8-bit core STM8L152C6T6 microcontroller developed by STMicroelectronics. With a new ultra-low leakage process and optimized architecture, it combines high performance with ultra-low power consumption and has outstanding advantages. The minimum circuit system designed by STM8L microcontroller is shown in the figure 5.

Angle sensor selection and design: This paper uses the angle sensor SCA100T-D01 chip produced by Finland VTI Company as the core chip for angle parameter acquisition. The SCA100T-D01 chip is a two-axis angle sensor based on MEMS (micro electro mechanical system) technology with a measurement range of -30° to +30°.

The SCA100T-D01 output is divided into analog output and digital output. Its digital output is 11 bits and the resolution is 0.035°. In order to improve the resolution of the sensor, a 24-bit ADC chip is added outside the sensor. The model is ADS1255. The circuit design of the sensor and ADC module is shown in the figure 6.

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Figure 5. STM8L microprocessor minimum system schematic

![STM8L microprocessor minimum system schematic](image)

Figure 6. SCA100T-D01 sensor chip circuit design

![SCA100T-D01 sensor chip circuit design](image)
The ADS1255 chip uses the CS chip select line SCLK clock signal line, DOUT data output line, and DIN data input line. The slave mode of SPI communication is the only mode in which ADS1255 works. Generally, a microprocessor such as this system uses STM8L microprocessor to control the registers on the ADS1255 chip. These registers read or write data through the serial port. ADS1255 writes data through the DIN pin and is valid on the falling edge of SCLK. ADS1255 reads data through the DOUT pin and is valid on the rising edge of SCLK. When the ADS1255 is idle, DOUT is in a high impedance state. ADS1255 chip circuit design is shown in Figure 7.

Serial communication module design: The data communication mode between the inclinometer and the external uses RS485 wired communication. This article uses the SN65HVD12 chip as the RS485 data communication interface chip. The SN65HVD12 chip contains a driver and receiver. The R and D terminals are the output of the receiver and the input of the driver respectively. They are connected to the RX and TX of the STM8L chip. The /RE and DE terminals are the enable and receive terminals respectively. Its circuit design is shown in Figure 8.

![Figure 7. ADS1255 chip circuit design](image1)

![Figure 8. SN65HVD12 chip circuit design](image2)

The PCB size of the inclinometer needs to meet the external mechanical structure size requirements. The PCB layout is designed using Altium Designer software tools. The PCB layout of the inclinometer is shown in Figure 9. The designed PCB layout is a 2-layer board design with a minimum line width of 8 mils, a minimum line spacing of 8 mils, and a minimum via size of 16 mils. It is a PCB with a high wiring density.
3.3. Inclinometer software design

The software development work of this topic is completed in the IAR FOR STM8 v1.3 programming environment, and the language used is C language. When designing the software function, it is necessary to consider the whole process. The overall design flow of the software is shown in Figure 10.

The task of the inclinometer is to collect angle and temperature data information in real time and upload it to the communication node. For the SPI communication between the STM8L microprocessor and the angle sensor chip SCA100T, the system uses two methods, active access and passive access. The data collected by the angle sensor chip SCA100T can be read by the STM8L microprocessor in a fixed period. If the collected parameters are within the standard range, the data will not be actively transmitted. According to the system instructions, the sensor performs the following tasks: requesting retransmission, obtaining a MAC address, modifying the MAC address, reading the working status, and reading the working mode [9,10].

![Figure 10. Main program flow chart](image-url)
3.4. External structure design of inclinometer

By using AutoCAD software, the external structure of the inclinometer is designed as shown in Figure 11. Structural design needs to consider the following aspects:

A. Made of stainless steel. The inclinometer is installed in a humid underground environment for a long time. In order to ensure the accuracy of the internal angle sensor and the rigidity and strength of the equipment subjected to the deformation pressure of the soil, it is made of high-strength stainless steel.

B. The size is suitable. Considering the starting point for easy installation and use, the inclinometer has a length of about 1000 mm, a maximum outer diameter of about 50 mm, and an inner diameter slightly larger than the board size, about 35 mm.

C. Roller and eyelet design. A pair of rollers are designed at each end of the inclinometer, and a lifting hole for pulling is designed at the top end. The roller structure is composed of a fixed wheel and a movable wheel controlled by a spring. During the installation process, the inclinometer is lowered by a steel rope passing through the hanging hole, and the roller is free to slide up and down in the slot of the mounting tube, and also plays a fixed direction.

D. Direction is determined. For the position where the angle sensor is installed, the angle sensor circuit board is fixed by two vertical studs in the tube, and the direction must be exactly the same as the standard direction of the angle sensor. The direction of the tube should be consistent with the direction of the internal direction.

4. Device function detection

The physical map of the inclinometer device used to measure surface displacement is shown in Figure 11.

![Inclinometer equipment](image)

Figure 11. Inclinometer equipment

The angle data sampled by the 24Bit ADS1255 chip, the angle data directly output from the angle sensor digital output interface, and the temperature data output by the inclinometer. The above results were simply processed by digital methods. See Table 1. for the comparison of the mean, variance and standard deviation of the AD chip.

It can be seen from the comparison in Table 1. that after increasing the 24BitADS1255 chip, the data resolution of the inclinometer is greatly improved, the fluctuation range of the data becomes smaller, and the value is more accurate. It has been verified that the designed inclinometer equipment can better measure the angle data and meet the project requirements.
Table 1. Comparison of angle sampling data before and after adding 24Bit ADS1255 chip

| Data       | Angle data after adding AD chip | Angle data without AD chip |
|------------|---------------------------------|-----------------------------|
|            | X direction                     | Y direction                 | X direction | Y direction |
| Mean       | -12.51971176                   | 15.07542941                | -12.68909412 | 14.99577059 |
| Variance   | 1.3128E-06                     | 2.70208E-06                | 0.001545717 | 0.003244941 |
| Standard   | 0.001145776                    | 0.001643799                | 0.039315608 | 0.056964383 |

5. Summary
The inclinometer equipment for slope monitoring was designed and designed. Using the angle measurement principle of SCA100T-D01 chip, the basic functions of the inclinometer equipment were realized through hardware design, software design and external structure design. The design measures such as power supply circuit design, software filtering, temperature compensation, lifting resolution, zero point correction, and watchdog circuit are adopted to improve the system stability, high precision and resolution of the inclinometer. The slope monitoring system applied to specific engineering practice is designed. The whole process from the whole system structure to the development and installation of the main equipment has been comprehensively studied and considered. It is economical, safe, reliable, simple and feasible, advanced and applicable, and stable in performance. System design was carried out in multiple dimensions. The digital inclinometer studied has certain application significance.

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