The device and experimental study of the monitoring of the layered soil settlement

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Abstract. In order to solve the problems of large measurement error, low efficiency, complex equipment operation and difficult maintenance of layered soil settlement, this paper designed a new monitoring device of layered soil settlement based on Hall effect. A number of Hall elements are arranged on the monitoring circuit board at equal spacing, and the circuit board is fixed in the aluminum tube and sealed. The aluminum tube with multiple settlement magnetic rings is drilled into the earth vertically, and the settlement magnetic rings are distributed in different soil layers. The settlement of the soft soil will move the magnetic ring, causing its position to change, which will cause the change of magnetic flux density around Hall element, and the output voltage of Hall element will also change, and then the voltage signal will be transmitted to Hall signal concentrator through RS-485 bus communication mode. The Hall signal concentrator stores the signal in FLASH and communicates with the upper computer through using the LORA wireless communication module. Through data processing and model analysis in the upper computer, the function between Hall voltage and variation of displacement of the magnetic ring is fitted. Many experimental results indicated that the error of the monitoring device of layered settlement is within 1.0567mm, and the accuracy is high. It can provide real-time monitoring to different soil layers, and the data can be exported at any time, so it has a wider application prospect.

1. Introduction

Geological conditions such as soil foundation, dam foundation and house foundation are very complex and unpredictable [1], so people often need to monitor the settlement of soft soil frequently in the process of construction to ensure the construction quality. At present, the methods used to monitor the settlement of soft soil are mostly infrared monitoring and laser detection [2]. Most of the settlement monitors used by them are to monitor the total settlement displacement of the whole soil foundation, while there is a lack of effective means for monitoring the subsurface layered settlement. Now people commonly used a class of simple settlement instrument to implement layered settlement monitoring. The simple settlement instrument is used to measure the settlement displacement by slowly lowering the probe along the settlement tube with a rope with a measuring scale [3]. So it’s always accompanied by all sorts of problems, such as low efficiency, poor reliability and instrument automation, longer time of data acquisition [4]. And all these problems will ultimately affect the quality and efficiency of construction.

Now in order to solve these problems raised above, this paper put forward a new method of measurement. It’s based on hall effect instead of controlling the rope manually. Through using Hall element array to implement 24-hour on-line real-time monitoring of layered soil settlement, this new
method of measurement helps to effectively avoid the construction of frequent monitoring and reduce the cost and difficulty of quality inspection.

2. Overall scheme design of soil layered settlement device

The concrete method of layered settlement monitoring of the soil is as described next. A number of Hall elements are arranged on the circuit board at equal spacing. And fix the circuit board in the settlement tube. The settlement tube is fixed on the bedrock where no settlement displacement is assumed to occur. Multiple settlement magnetic rings are nested on the settlement tube at a certain distance, and each settlement magnetic ring corresponds to a different soil layer. The subsided soil layer drives the corresponding settlement magnetic ring to produce settlement displacement. The magnetic flux density around the Hall element node will change. According to the Hall effect, the Hall element node will output a specific voltage [5]. The analog voltage will be converted to digital voltage through A/D conversion chip, and then transmitted to the Hall signal collector. The Hall signal collector waits for the instruction of the Hall signal concentrator, and transmits all the voltage values of the Hall nodes to the Hall signal concentrator through RS-485 bus communication [6]. The Hall signal concentrator will transmit the data from each collector to do preliminary filtering processing, and analyze the number of settlement magnetic rings and settlement tubes, and store these information in Flash. The Hall signal concentrator communicates wirelessly with the upper computer and uploads information stored in Flash. The upper computer processes and analyzes these data by modeling, and displays the initial position of the settlement magnetic ring, settlement displacement and other information. The design can realize remote real-time online monitoring of soft soil settlement displacement, so as to guide engineering construction quickly and efficiently. The overall scheme design is shown in Figure 1.

During the construction of the project, a number of settlement tubes and settlement magnetic rings
can be combined according to the specific needs, and the settlement magnetic rings can be buried in different soil layers at a certain distance to achieve the purpose of layered settlement monitoring of soil. The accuracy of settlement displacement monitoring is determined by the number of settlement magnetic rings.

3. Hardware circuit design

3.1. Hardware design of Hall signal collector

The Hall signal collector collects and detects the voltage value isolated by the filter and voltage follower on the circuit board, and uses the 12-bit analog-digital converter TL2543 chip to convert the analog voltage value into digital voltage value, which is transmitted to the main control chip STM32F103C8T6 of the Hall signal collector [7]. Through RS-485 bus communication, a group of collected digital signals will be sent to Hall signal collector to analyze and process. The hardware design of Hall signal collector is shown in Figure 2.

![Figure 2. hardware design of Hall signal collector](image)

3.1.1. Hall sensor

The Hall sensor used in the Hall signal collector is SS495A1. It is a new type of Hall effect integrated circuit chip, with higher temperature stability and sensitivity, which supply current as low as 7mA at 5VDC power supply. In addition, SS495A1 has low power consumption [8], small size, high cost performance, simple operation and so on. The characteristics of conversion of its output voltage and external magnetic flux intensity are shown in Figure 3.
Figure 3. SS495A1 conversion characteristics

Figure 4 shows that the transformation characteristics of SS495A1 are linear under ideal conditions. The conversion formula of its output voltage and magnetic flux intensity is as follows:

\[ V_{out} = 0.003125B \]  

(1)

Vout is the output voltage of SS495A1, B is the magnetic flux intensity, and GAUSS is the unit of magnetic induction intensity.

3.2. Hardware design of Hall signal concentrator

Hall signal concentrator, which receives all voltage signals from all Hall signal collectors through RS-485 bus communication mode, carries on the preliminary filtering processing to the data, and analyzes the number of collectors and settlement magnetic rings. The concentrator writes the statistics into the FLASH-chip W25Q32 and communicates with the PC through the LORA wireless communication module.

When the concentrator receives the corresponding instruction from the upper computer, it will read out the data stored in FLASH and transmit it to the upper computer. Data processing and modeling analysis will be done by the upper computer. The Hall signal concentrator is shown in Figure 4.

4. System software design

The software of the soil layer settlement device mainly includes the design of the remote monitoring platform of soil layer settlement, the software of Hall signal concentrator and Hall signal collector.
4.1. Software design of Hall signal collector
Hall signal collector uses C language as the programming language, Keil5 as the development platform to write the program. First of all, it initializes each module of the collector and the memory pool. It uses Modbus communication protocol, RS-485 communication mode, Flash, TL2543 analog-to-digital conversion function and so on. Thereafter, the collector waits to receive the data frame sent by the Hall signal collector on RS-485 bus, analyses the data frame according to the Modbus communication protocol, and transmits the voltage data to the hall collector if the command of collecting the current Hall element voltage is obtained.

4.2. Upper computer interface software design
The upper computer interface takes Qt as the framework and C++ as the programming language [9]. Qt is a cross-platform C++ Graphical User Interface application development framework. Qt is an object-oriented framework that uses special code to generate extensions.

The upper computer interface of the device is very easy to operate. The upper computer, which processes and models the voltage data from the Hall signal collector uses curve fitting to find the corresponding relationship between the settlement displacement and the collector voltage signal, and displays the initial position and settlement distance of the settling magnetic rings, and draws the change curve of multiple magnetic rings’ positions over time in real time. The CSV or Excel data of multiple magnetic rings over time can be exported and saved, so as to analyze the layered settlement of soil.

4.3. Software design of Hall signal concentrator
Hall signal concentrator is also used in Keil software platform, using C language programming. The first step is to initialize various modules, such as delay function, memory pool, Lora module, Modbus communication protocol, OLED, Flash, stepper motor, etc. Since then, the hall signal concentrator enter standby mode and wait for a command computer PC sends data, if the data instructions for running mode, then open the timer interrupt, each time to the timer set time, entered the timer interrupt service functions, to the hall collector send instructions of hall element voltage data received after the feedback voltage data, data will be temporarily stored in flash, finally all voltage data read from the FLASH and sent to the upper computer analysis processing.

5. Experimental data processing and result analysis

5.1. Experimental data processing
In the calibration mode of Hall signal concentrator, the stepping motor pushes forward the magnetic ring 1mm every time under the control of timer interrupt to record the voltage values of all Hall elements at the moment. The concentrator integrates the position of the magnetic ring with the voltage values of all Hall elements and uploads them to the upper computer. The data were analyzed and modeled by the upper computer, and the function relationship between the position of the magnetic ring and the voltage value of Hall element was established. It can be known from the transformation characteristics of SS495A1.

However, the function relationship between magnetic flux intensity B and magnetic ring settlement displacement X as follow.

\[ B = f(X) \]  

This function cannot be obtained directly [10], because the variation of magnetic flux intensity distribution caused by the displacement of the settlement magnetic ring can only be analyzed qualitatively. Therefore, it is necessary to find the functional relationship between the settlement displacement X and the output voltage of Hall element Vout.

\[ X = f(V_{out}) \]
A large number of experimental data are needed, and curve fitting method such as least square method or analytical expression approximation of discrete data are adopted to fit the function expression between the settlement displacement X and the output voltage of Hall element Vout.

5.2. Result Analysis
Start the device of the monitoring of the layered soil settlement, and take the position of the magnetic ring at the initial moment as the base position to move a single settlement magnetic ring. Move the settlement magnetic ring 20mm each time, and record the actual position of the settlement magnetic ring and the measured value displayed by the upper computer. The error of each group of data was calculated by comparing the actual value with the measured value. The experimental test results are shown in Table 1.

| number | measured settlement displacement/cm | actual settlement displacement/cm | error/cm |
|--------|-----------------------------------|----------------------------------|----------|
| 1      | 0                                 | 0                                | 0        |
| 2      | 1.89207                           | 2                                | -0.10793 |
| 3      | 2.77611                           | 4                                | -1.22389 |
| 4      | 5.86969                           | 6                                | -0.13031 |
| 5      | 8.09455                           | 8                                | 0.09455  |
| 6      | 10.0868                           | 10                               | 0.0868   |
| 7      | 12.1181                           | 12                               | 0.1181   |
| 8      | 14.3502                           | 14                               | 0.3502   |
| 9      | 16.2644                           | 16                               | 0.2644   |
| 10     | 18.2089                           | 18                               | 0.2089   |
| 11     | 20.1720                           | 20                               | 0.1720   |

After removing the gross error, the average value of the error is 1.0567mm. It can be concluded from the experimental results that the layered settlement monitoring device proposed in this paper can realize the displacement monitoring with high precision and high reliability.

6. conclusion
In this paper, the device of the monitoring of the layered soil settlement can monitor the layered settlement displacement of soft soil online with high efficiency, high precision and real time. This device put forward a new measuring method based on Hall effect. Compared with the traditional steel tape or drawstring mechanical detection, this measuring method saves labor cost and can simultaneously monitor the settlement displacement of multiple locations and different soil layers. This device has a high degree of automation, which can monitor the settlement displacement of soft soil all day long, effectively guide the construction of the project and timely prevent disasters. The device can also realize data sharing through the network, and carry on network, remote and real-time monitoring to the settlement displacement of many places.

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