Development of Portable Shallow Hole Inclinometer in Coal Mine

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Abstract: Due to the special requirements of borehole measurement work in coal mines, in this paper, a portable shallowhole inclinometer is developed in response to the current situation of shallow borehole trajectory measurement relying on the pushing of drilling machine. This instrument is mainly composed by three parts of inclinometer probe tubes, orifice display controllers, and conveying rods. The probe tube can be used to measure the attitude parameters such as the inclination, azimuth and tool facing angle of the borehole, and the orifice display controller works synchronously and records the drilling depth and measuring time. Finally, the track of the current borehole can be displayed in the mine. The test results show that the instrument is stable, reliable, and practical.

1. Introduction
During ordinary drilling construction in coal mines, due to changes in the occurrence status of coal and rock layers, construction techniques, etc., the drilling trajectory will be deviated from the original design direction, misleading geological analysis, and causing hidden safety hazards. The use of mining borehole inclinometers solves this technical problem very well. At present, the drilling trajectory measuring instruments in coal mines are mainly divided into two types: real-time measurement and storage type measurement. The real-time measurement is usually used in the directional drilling process, which has achieved the purpose of controlling the drilling trajectory in real time. The storage type measurement is usually used in the rotary drilling process, which measures the trajectory of the drilling hole after the hole is formed to verify the drilling construction quality [1-5].

A great deal of work in underground coal mines is drilling holes such as working face drilling and water exploring and discharging drilling, which are usually constructed by ordinary rotary drilling technology. This process is characterized by fast construction speed and shallow construction hole depth (about 150m). Existing trajectory measuring instruments have to be connected with a drill pipe and pushed by a drilling rig when measuring. For shallow holes or sites where the drilling rig is difficultly access, this kind of measurement process is time-consuming and laborious, and lacks a highly efficient and convenient trajectory measurement equipment. In this case, the development of a portable shallow hole inclinometer that does not rely on a rig and is easy to carry with will better to satisfy the actual work needs.

2. Working principle
The inclination is the angle between the tangent to the current point of the borehole and the horizontal plane, and the measurement range is [-90°, 90°]; The tool facing angle is the included angle of rotation
along the borehole axis, and the measurement range is \([0°, 360°]\); The azimuth is the angle between the current borehole projection in the horizontal plane and the north direction, and the measurement range is \([0°, 360°]\). By installing three accelerometers and three magnetic sensors on the three basic coordinate axes, the attitude measurement system of the basic drilling inclinometer is formed \([6-7]\), as shown in Figure 1.

![Figure 1: Sensor installation mode](image)

\[ G_X, G_Y, G_Z \] are the measured values of the gravity field in the \(X\)-axis, \(Y\)-axis, and \(Z\)-axis of the instrument coordinate system. Therefore, the expressions of the inclination angle and the tool facing angle are Equation 1 and Equation 2, respectively.

\[
\tan \theta = \frac{-G_Y}{(G_X^2 + G_Z^2)^{1/2}} \\
\tan \phi = \frac{G_Y}{G_Z}
\]

(1)  

(2)

Where: \( \theta \) is the inclination of the drilling tool, and \( \phi \) is the tool facing angle of the drilling tool.

\( B_X, B_Y, B_Z \) are the measured values of the geomagnetic field on the \(X\)-axis, \(Y\)-axis, and \(Z\)-axis in the instrument coordinate system. Therefore, the expression of the azimuth can be obtained as Equation 3:

\[
\tan \psi = \frac{G_0(B_YG_X - B_XG_Y)}{B_Y(G_X^2 + G_Z^2) - G_Y(B_XG_X + B_XG_X)}
\]

(3)

Where: \( \psi \) is the azimuth of the drill.

**3. Hardware design of portable shallow hole inclinometer**

The portable shallow inclinometer consists of a shallow hole inclinometer probe tube, an orifice display controller and a conveying rod. When working downhole, the back end of the synchronized measuring probe can be connected to the transmission rod and then sent to the borehole to start measurement. The measuring probe measures and records the drilling trajectory parameters (inclination angle, azimuth angle, etc.) in real time according to the set time interval. The orifice display controller stays outside the borehole, and after each time a drill rod is fed in, in the gap of connecting the drill pipe, the operator records the measurement time and drilling depth at the set sampling interval. After the drilling measurement is completed, lift the drill to take out the measurement probe, and transmit the data in the probe tube to the orifice display controller through Bluetooth wireless transmission. The calculation and processing of the processing software automatically generate the trajectory of the drilling, and graphic display (up and down deviation, left and right deviation).

**3.1 Shallow hole inclinometer probe tube**

(1) Probe tube hardware design

The azimuth measurement uses a magnetic sensitive sensor to determine the orientation and attitude of the probe tube based on the geomagnetic field; the inclination measurement uses an acceleration sensor to determine the pitch angle of the probe tube based on the acceleration of gravity.
The electrical signals generated by the sensors are calculated and processed by the MCU control unit into digital storage. The communication unit transmits the data to the orifice display in a standard serial format for data processing and curve report display and printing. The overall working block diagram of the probe is shown in Figure 2.

(2) Probe tube software design
The probe software adopts the idea of modular design to complete the driver of each functional device, and finally realizes the system's data measurement calculation and storage. The system flowchart is shown in Figure 3. After power-on initialization, the probe communication module waits for the command of the orifice display controller. If it receives a collection command, it returns the measurement result of the current data acquisition unit and enters the standby mode, otherwise it continues to wait.

3.2 Orifice display controller
(1) Orifice display controller hardware design
The display controller is the overall control device of the measurement system, and also the man-machine interaction interface between the driller and the measurement while drilling system. The user sends commands such as synchronization, configuration, and data extraction to the probe. At the
same time, the probe responds accordingly after receiving the command, and sends the corresponding data information to the orifice display controller. The orifice display controller displays the received data information through calculation and processing, and displays it in the form of numbers and graphics (cross-section graph and plane graph). The orifice display controller includes the following parts: power module, communication interface module, storage module, key control and display module.

![Hardware components of display controller](image)

(2) Orifice display controller software design

The graphical user interface is a key part of the design of a handheld aperture display controller for mining. The main contents of this software design include the transplantation of the emWin graphics library on the STM32 platform and the design of data acquisition control programs based on the emWin graphics library. The transplantation of emWin graphics library can be applied to the embedded multi-tasking environment, which can not only play real-time priority, but also achieve a good human-machine interaction.

The program flowchart is shown in Figure 5.

![Software flow chart of display controller](image)
3.3 Conveying rod
The probe in this article needs to be manually sent to the bottom of the hole for measurement by a pushing device, and the pushing device will be connected to a maximum length of about 150m, which requires the reliability and weight of the pushing device connection. Therefore, this research uses carbon fiber material as the main material of the pushing device. Each pushing device is 1m in length and 22mm in diameter. They are connected by threads and each mass does not exceed 180g, which ensures reliable structural connection and reduces the weight of the whole pushing device.

4. Field Test

4.1 Accuracy test
In order to verify the accuracy of the portable shallow hole inclinometer, a ground accuracy test was performed in the drilling equipment testing laboratory. This test used a high-precision three-axis non-magnetic digital inclinometer adjustment device for testing.

| Inclination calibration value(°) | Measured value(°) | Tool facing angle calibration value(°) | Measured value(°) | Azimuth calibration value(°) | Measured value(°) |
|---------------------------------|-------------------|--------------------------------------|-------------------|-----------------------------|-------------------|
| -90                             | -89.7             | 0                                    | 0.2               | 0                           | 0.1               |
| -60                             | -60.1             | 45                                   | 45.4              | 45                          | 44.8              |
| -45                             | -45.1             | 90                                   | 89.8              | 90                          | 89.3              |
| -30                             | -29.8             | 135                                  | 134.6             | 135                         | 133.9             |
| 0                               | 0.2               | 180                                  | 179.7             | 180                         | 180.6             |
| 30                              | 30.2              | 225                                  | 225.2             | 225                         | 224.7             |
| 45                              | 45.2              | 270                                  | 270.4             | 270                         | 270.5             |
| 60                              | 60.1              | 325                                  | 325.3             | 325                         | 324.8             |
| 90                              | 90.3              | 360                                  | 359.9             | 360                         | 359.8             |

As can be seen from Table 1, the accuracy of the portable shallow hole inclinometer is high, and it can meet the accuracy index proposed by the instrument design.

4.2 Industrial test of Dahebian coal mine
In order to further verify the stability and reliability of the portable shallow-hole inclinometer, underground industrial tests were carried out in the No. 3 borehole in the rock lane of Dahebian coal mine in Guizhou. In this test, the measurement interval was 4m, and the probe reached the bottom of the hole at 116m. During the test, the measurement of the data was stable, and the measurement results reflected the trajectory of the borehole. The measurement results are as follows:

| Depth(m) | Inclination(°) | Azimuth(°) |
|----------|----------------|------------|
| 4        | 8.25           | 304.21     |
| 16       | 8.12           | 301.52     |
| 28       | 4.87           | 298.79     |
| 40       | 1.09           | 295.12     |
| 52       | -0.54          | 292.41     |
| 64       | -0.42          | 290.92     |
| 76       | 2.9            | 289.8      |
| 88       | 3.89           | 288.1      |
| 100      | 4.15           | 286.43     |
| 116      | 3.35           | 286.65     |
5. Conclusion
The borehole inclinometer has been widely used in coal mine underground construction and gas drainage, which greatly improves gas drainage efficiency and reduces coal mine safety accidents. In this paper, a set of portable drilling trajectory measuring instruments is developed, with an inclination measurement range of -90° to 90°, an error of ± 0.3°, an azimuth measurement range of 0° to 360°, and an error of 1.0°. It has the characteristics of small size, light weight, low power consumption, and easy to carry, which can be used to measure by the push device after the hole is formed. The portable display controller generates the drilling trajectory map under the well, which can better monitor the construction quality of drilling. Through industrial tests in underground mines, it has verified the characteristics of the developed instrument with superior performance, simple operation, stability and reliability. It supplements the existing underground borehole trajectory measurement system and provides new equipment for underground coal mine gas treatment and drilling construction.

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