INTRODUCTION

Crustal stress-strain observation possesses an important status in analysis of seismic surveillance and tectonic stress field. Crustal stress-strain observation includes observation on horizontal stress-strain, vertical stress-strain and inclined strain. Clinometer is a fundamental instrument studying the geophysical process and geodynamics according to its observation on crustal inclination and deformation. It contains very important significance to seismic precursor observation instrument: Measuring spans are small, and the requirements on observation environment are strict. This clinometer is in inverted pendulum design and uses CCD sensor to monitor ground inclination variations. It is able to reduce installation cost while effectively avoiding the main influence left by ground noise. As a result, the measuring span can be increased and the ability to monitor crustal deformation can be effectively improved.

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Design and Realization of a New-type BSQ Inverted Pendulum Clinometer

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ABSTRACT: In the preparation and generating process of a strong earthquake, the inclination changes of the ground formed by crustal structural deformation can be striking. Generally, the abnormality can greatly exceed the measuring spans of most clinometers which can be found on the market currently. This paper proposed and developed a new-type BSQ inverted pendulum clinometer aiming at solving the problems of current precursor observation instrument: Measuring spans are small, and the requirements on observation environment are strict. This clinometer is in inverted pendulum design and uses CCD sensor to monitor ground inclination variations. It is able to reduce installation cost while effectively avoiding the main influence left by ground noise. As a result, the measuring span can be increased and the ability to monitor crustal deformation can be effectively improved.

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which can be found on the market currently. As a result, it is difficult to record the overall process of complete ground inclination variations formed by seismic generation. Based on this situation, we developed BSQ inverted pendulum clinometer. With its main body working underground, BSQ inverted pendulum clinometer can be installed in short holes under the ground, reducing the influence from ground environmental noise to a large extent. Based on the above, BSQ inverted pendulum clinometer is in favor of analyzing the ground inclination background information and recognizing the precursor abnormality. In addition, compared with other borehole clinometers, the installation cost of BSQ inverted pendulum clinometer is greatly lessened while its maintenance is more convenient.

2 COMPOSITION AND WORKING PRINCIPLE OF BSQ INVERTED PENDULUM CLINOMETER

BSQ inverted pendulum clinometer is composed of inverted vertical installation and CCD sensor among which inverted vertical installation includes oil drum, floating body set, connecting rod, chuck, vertical line and anchor block. The floater of the installation is of closed type. It is a metal annular casket in a shape similar to oil drum. In order to make enough room for floater in oil drum, the external diameter of floater shall be smaller than that of oil drum while its inner diameter shall be bigger than that of oil drum. The height of floater shall be slightly lower than that of oil drum. The connecting rod of floater is a hollow metal round bar with two nuts on both ends connecting floater stand. On the bottom of floater connecting rod, there is a chuck with three chip cards clipping vertical line. The upper end of vertical line is fixed on connecting rod of floater while its lower end is connected with anchor block.

The lower end of vertical line is deeply anchored inside bed rock by BSQ inverted pendulum clinometer while its upper end is fixed on the clip head of floating body set. Steel wire is tensioned by the buoyancy force generated from the fluid inside oil drum as shown in Figure 1(a). In line with principle of flotation, steel wire will automatically return to vertical status so as to measure the absolute deformation of ground with respect to bed rock in depth. After the measured object is inclined by $\Delta\psi$, vertical line will automatically return to vertical status in the new position as shown in Figure 1(b). Use practical measuring instrument and technology to measure the arc $\Delta X$ swept by vertical line before and after the measured object is inclined, and then the inclination variation $\Delta\psi$ of the measured object can be detected. The relation between ground inclination $\Delta\psi$ and arc $\Delta X$ swept by vertical line of pendulum bob is $\Delta\psi=\Delta X/L$ (rad). In practical application, use super alloy with ultralow-thermal expansion dilatation coefficient as vertical line and use CCD sensor to detect $\Delta X$.

![Figure 1. Schematic diagram of BSQ inverted pendulum clinometer.](image)

3 INCLINATION SENSOR

Photoelectric image sensing method is applied in sensor. Use CCD to develop photoelectric integrated displacement sensor for micro movement detection. CCD is made of a kind of high-sensitivity semiconductor materials which can transform light rays into electric charges. The instrument can switch electric charges into digital signals through analog-digital converter chip. The comparator circuit of the instrument can realize bright and dark binaryzation of pixel. Single chip and its peripheral circuit can process and store binaried image metadata, and thus obtain the measurement data. There are several thousand of photoelectric sensors arrayed in precision inside CCD. Under the function of driving and pulse control, the optical images on CCD window can be converted into transmittable video scanning signals and then be outputted in form of quantized data. The principle structure of sensor is shown in Figure 2:

![Figure 2. Schematic diagram of the principle of CCD sensor.](image)

CCD sensor is composed of two parts—parallel light source and CCD optical receiver. Both parallel light source and CCD optical receiver are fixed on
instrument baseboard. Light beams sent from point light source are converted into parallel light illuminating vertically on CCD optical receiver through lens. Vertical line is placed in light path and its shadow is projected on optical receiver for CCD to recognize, process, and quantize into data corresponding to the location of vertical line. As data size conversion of vertical line location is realized through CCD sensor, there is no electrical drifting existing. During its working process, single chip completes the programable driving, data collection, data processing, and data transmission of CCD device. See Figure 3 for the working diagram of CCD device.

4 MAIN TECHNICAL PARAMETERS OF INSTRUMENT

The main technical parameters of BSQ inverted pendulum clinometer are as follows:
- Resolution ratio: 0.1 second of arc
- Range: ±10 minute of arc
- Linearity: 0.5 %FS

Electrical drifting: N/A
Status display: Double-circuit with 4-position LED
Telemetering interface: RS485
Power supply: AC 220V±15%, 50Hz
Consumption: 5W
Environment temperature: −10°C – +40°C
Environment humidity: 95%RH

5 APPLICATION OF CLINOMETER IN CRUSTAL DEFORMATION

The surveillance system of BSQ inverted pendulum clinometer controls clinometer to collect data through PC104. Working status of clinometer can be checked and parameters can be set on webpage while data can be directly downloaded through webpage or Ftp. Precursory station network system is applied to realize unified data management. BSQ inverted pendulum clinometer is a digital clinometer with medium observation precision. Its resolution ratio is 0.1 second of arc and its measuring span is ±10 minute of arc. It can be used to monitor the ground inclination deformation.
under strong earthquake. BSQ inverted pendulum clinometer has been installed and put into practice in Beijing Changping seismostation since January, 2010. Since its operation, it has observed rich crustal deformation data, such as slow variations in ground inclination and co-seismic responses. Analysis will be given below according to the observation data collected after 4 months since the clinometer started working. Figure 3 and Figure 4 are the curves of the minute value data on EW direction and NS direction observed from February 1st, 2010 to May 31st, 2010. From the figures, we can find that deformation variation information of multi co-seismic responses on both EW direction and NS directions has been observed. As there are various reasons for different earthquakes, such as earthquake location, focal depth and geological structure, the observed co-seismic responses can be different. Figure 5 is the record observed by BSQ inverted pendulum clinometer of the 7.1Ms earthquake happened in Yushu County, Tibetan Autonomous Prefecture of Qinghai Province (epicentral position: 33.2°N, 96.6°E; original time of earthquake: 2010-04-14 07:49:38). It can be seen that BSQ inverted pendulum clinometer contains larger observation span and can observe rich ground deformation data, such as slow variations in ground inclination and co-seismic responses, enriching borehole stress-strain observation data greatly.

6 CONCLUSIONS
Application practice has shown that BSQ inverted pendulum clinometer is stable and reliable in performance. The instrument can observe the breaks in de-
clivity of both directions: EW and NS. It belongs to wide-range oblique observation instrument in earthquake precursor observation. Little impact from ground environment would be left on the instrument, and thus it can well record the abnormal crustal changes before and after earthquake, providing rich data and proof for seismic research work.

ACKNOWLEDGEMENT

This paper is financially supported by Special Fund for Basic Scientific Research Business of Central Public Research Institutes (GN: ZDJ2014-02).

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