Application of Capacitive Strain Transducer in Geostress Survey

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ABSTRACT: In order to meet the requirements of high precision and large measuring span in borehole strain measurement, RZB capacitive strain transducer is designed by establishing the relationship between capacitance and micrometric displacement. A preliminary analysis was conducted on the data observed through Sichuan Shimian Station RZB capacitive borehole strain gage by applying the transducer in the borehole strain gauge. The analysis results show that RZB capacitive borehole strain gage is high in observation accuracy and can record clear solid tides and broadband strain seismic waves.

Keywords: crust stain; borehole strain gauge; capacitive transducer

1 INTRODUCTION

Crust can generate stress concentration and cause earthquake during deformation. The relation between earthquake and crustal deformation is the most direct. As earthquake is caused by change in crustal stress, observation on change of crustal stress must be done to study and forecast earthquake. There are two main kinds of instrument that can directly observe crustal strain. One is to measure change in base length, such as extensometer and laser strain meter. The other is borehole strain gauge used to measure borehole deformation. Compared with strain meter which is used to measure change in base length, borehole strain gauge contains many advantages, such as little influence from earth surface, little terrain limit, high precision, wide frequency band, low cost, convenient installation, and simple maintenance. Since Xingtai Earthquake that occurred in 1966, China has started using piezomagnetic elements to develop observation on borehole stress. Internationally, Sacks from American Carnegie Research Laboratory and Evert son from University of Texas made the first borehole strain gauge in September, 1968. With the development of borehole strain gauge accomplished in China, Japan, and Australia one after another, borehole strain gauge has been in rapid development and increasingly improvement. In recent years, international earth scientific community has paid great attention to the multi-component observing technology for deep well wide band, such as American PBO Plan.

Since 1960s, domestic borehole stress-strain observation technology has made a great progress in half century. RZB capacitive borehole strain gauge has high observing precision and can measure each multi-component dynamic change of crustal horizontal strain field. It also can complete on-site proving and can be installed in deep well through cement fixing, making it very applicable for borehole installation and stress observation.

2 STRUCTURE AND FEATURES OF RZB CAPACITIVE BOREHOLE STRAIN GAUGE

RZB capacitive borehole strain gauge is an instrument to record crustal stress and dynamic changes in strain field. It is installed in rock borehole. Special-type cement is applied as coupling medium. By measuring changes in pore diameter of rock borehole, RZB capacitive borehole strain gauge can measure strain changes. It contains high observing precision and stability, and is able to record clear solid tides and crustal deformation during earthquake preparation process.

Measuring system of RZB capacitive borehole strain gauge is consisted of down-hole strain probe, auxiliary observing probe, and data acquisition unit. Strain probe is installed in borehole with inner diameter of 130mm. Special-type cement coupling shall be applied. Figure 1 is the schematic diagram of down-hole probe of RZB capacitive borehole strain.
gauge measuring system in borehole. No.1 to No.4 horizontal strain transducers are installed inside strain probe. Arrange No.1 to No.4 transducers clockwise with an angle of 45° in between respectively. Two ends of a strain transducer shall be fixed on inner wall of probe. When steel cylinder of probe changes has deformation with borehole bedrock, strain transducer can make accurate measurement. Four capacitive displacement transducers shall be arrayed with angle of 45° in proper order. They can measure stress and strain on four horizontal directions at the same time, so as to accomplish the observation of stress-strain crustal deformation status inside borehole.

3 PRINCIPLES AND CALIBRATION OF CAPACITIVE STRAIN TRANSUDER

3.1 Working principles of transducer

4 capacitive displacement transducers are installed in down-hole borehole strain probe. Tri-electrode differential structure is applied in sensing element. Two differential variation capacitors constitute 3 paralleling metal counter electrodes. Transducers are installed on the probe walls of elastic steel cylinders with diameter of 102mm, coupled to the ground through special-type cement. With probe deformation under crustal stress, intervals between counter electrodes of capacitive transducers will have corresponding changes. Capacitance will change accordingly, so as to establish a relation between deformation and differential change in capacitance. Thus, we can accurately sense borehole deformation by measuring differential change in capacitance. See Figure 2 for the structural diagram of capacitive displacement transducer installed on elastic steel cylinder. d1 and d2 in Figure 2 respectively represent the distance between two neighboring capacitance plates. The sum of d1 and d2 is a fixed value which can decide sensitivity and dynamic range of transducer to a large extent. It is the optimal design accumulated through long-term experiment and practice. U refers to the displacement of capacitance plate 2 relative to capacitance plate 1 and capacitance plate 3. Capacitance plate 1 and capacitance plate 3 are fixed on A end of steel cylinder through transmit pole while capacitance plate 2 is fixed on B end through transmit pole. When steel cylinder is squeezed or deformed because of tension, d1 and d2 will change accordingly and form the relative displacement U between counter electrodes.

Figure 1. Schematic diagram of the measuring system of RZB capacitive borehole strain gauge.

Figure 2. Structural diagram of transducer.

3.2 Transducer and measuring circuit

As shown in Figure 2, tri-electrode differential structure is applied in transducer. It is made up of three metal plates. Tri-electrode stays in paralleling form with fixed intervals between counter electrodes on both sides and special processing is used to ensure intervals between counter electrodes remain the same as shown in Figure 3 that d1+d2=constant. Middle counter electrode is moving electrode and can generate displacement with outer wall of probe. Upper, middle and lower counter electrodes of transducer and ratio transformer constitute alternating-current bridge. N1 and N2 shown in Figure 3 represent the number of turns on both ends of ratio transformer tapping earth point. The total number of turns of ratio transformer is equivalent as 128 turns, meaning N1+N2=128. MCU control unit is imbedded inside strain probe to regulate center tapping earth point of ratio transformer, amplification factor of modulation and enlargement, A/D conversion operations, and bus transfer of data. MCU can regulate bridge circuit balance by regulating center tapping earth point of ratio transformer through changing N1 value. Location of earth point delivered to the ground is N1 value. Unbalanced signal of bridge circuit output by center counter electrode is delivered to the ground through data bus after being processed by pre-amplification, modulation amplification, phase sensitive detection, LPF (Low-Pass Filtering), and A/D conversion. In order to improve system reliability, two sets of identical program control systems are equipped. Only one set works at ordinary times. The other set is used to
completely disconnect cold standby with power supply. Data acquisition unit on the ground is in charge of recording and storing data transmitted through bus. As digital signals are transmitted through RS485 bus, data acquisition, transmission, and setting up are all completed by bus commands.

As the antedisplacement of signal processing circuit can make output signals of transducers enter modulation circuit as close as possible, amplification factor can be properly lowered while measuring precision remains the same. Therefore, the one-time dynamic regulation range of system can be greatly improved. The one-time dynamic regulation range RZB borehole strain measuring system is improved to be 120db. With the improvement of one-time dynamic regulation range, new-type borehole strain observation system will be in rare need of rebalance regulation in the future after formal observation is started which is very beneficial to strain observation on long-term large-scale dynamic range, station operating maintenance, and data continuous rate improvement.

3.3 Transducer calibration

![Figure 4. Transducer displacement calibration curve.](image)

After capacitive transducer is installed, calibration must be firstly conducted in laboratory. In calibration, transducer shall be fixed on calibration platform to record the output capacitance value. Figure 4 shows the relative displacement calibration curve between counter electrodes of transducer. It can be seen from the figure that when borehole reaches dynamic range of $10^{-4}$ magnitude, output linearity of transducer is still good. The black dots in the figure represent calibration measuring results; the straight line represents linear fitting result, and numbers inside the box are fitting functions and error. According to the definition of linear strain, the relative displacement between counter electrodes between transducer is $1\mu m$ for elastic steel cylinder with diameter of 102mm. The corresponding linear strain is about $9.8 \times 10^{-6}$.

4 APPLICATION OF TRANSDUCER IN CRUSTAL STRESS SURVEY

RZB capacitive borehole strain gauge is high in sensitivity and wide in strain observation range and one-time regulating range. Dynamic range of one-time zero setting can reach $\pm 2 \times 10^{-4}$ strain. Therefore, no more zero setting work is needed in 10 to 15 years after installation is completed in most cases. This feature makes it possible to record strain accumulation in a large time scale, making it very applicable for installation in deep-well borehole. In the following part, we will take the RZB capacitive strain gauge installed in Sichuan Shimian Station as the example to analyze and explain.

The RZB capacitive borehole strain gauge of Sichuan Shimian Station includes 4 horizontal strain measuring units, 1 system reference element, and electronic compass. System reference element and horizontal strain transducers share the same structure. However, system reference element will have no contact with elastic steel cylinder of down-hole probe. As a result, no influence will come from crustal stress change. The output can reflect the long-term stability and various electrical disturbance of system. Figure 5 shows the original horizontal strain data from April, 2013 to December, 2013. It can be seen from the figure that the instrument was in good working condition. Figure 6 shows the observing curve of Shimian Station solid tides. It can be seen from the observation curve that RZB capacitive borehole strain observing system has high observing precision and high SNR. It
can observe clear solid tides and is an ideal equipment for borehole strain observation.

RZB capacitive borehole strain gauge strain transducer observes crustal strain changes through the relative displacement between plate capacitors caused by measurement of change in borehole diameter. It has very wide frequency response features. Besides recording clear solid tide signals, observing system can also record strain seismic waves. Figure 7 shows the strain seismic waves of Lushan Earthquake happened on April 20th, 2013 recorded by Shimian Station RZB capacitive borehole strain gauge. Thus, it can be seen that RZB capacitive borehole strain observing system has wide observing frequency band. It can record both clear solid tides and part strain seismic wave data which can enrich observing data of borehole strain to a great extent.

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5 CONCLUSIONS

RZB capacitive borehole strain gauge applies advanced capacitive micrometric displacement transducer and bridge measurement technology with high-precision rate. It has high observation accuracy, high stability, high SNR (Signal to Noise Ratio), and broad observational spectrum. With the ability to record rich information about dynamic stress field activities of earth crust, RZB capacitive borehole strain gauge can provide abundant data and proofs for earthquake research work.

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