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Application of Piezoelectric Materials in Structural Health Monitoring of Civil Engineering Structure

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Aimed at the high water and high alkali environment in concrete, a small embedded piezoelectric ceramic sensor for monitoring reinforced concrete structure is developed, and its basic performance parameters are given. According to the working principle of the charge amplifier, the formula of the output voltage of the piezoelectric ceramic sensor subjected to vertical uniform force is deduced according to the piezoelectric equation. According to the test results of the sensor performance, the performance parameters of the sensor with different sizes of piezoelectric ceramics are compared.

1. Introduction

Civil engineering structures have a long service life and are difficult to replace once they are built. However, the performance of any civil structure can deteriorate over time. This is mainly due to aging, excessive use, overloading, environmental erosion and lack of maintenance and inspection methods (Tseng et al., 2014; Marković et al., 2015). An effective structural health monitoring system for civil engineering can diagnose the location and extent of defects (cracks, rust, etc.) in real time so that the structure can be repaired and reinforced in time to ensure structural integrity and safety (Rahim and Ahmad, 2017). At present, many structural health detection methods are applied to various civil engineering structures or their components. Such as classical static strain (or displacement) testing, vibration identification methods, and non-destructive testing methods: acoustic emission, ultrasonic, impedance, infrared thermal imaging, pulse radar and X-ray (Song et al., 2016). But most methods are qualitative, and it is difficult to carry out real-time detection. Smart materials such as piezoelectric materials, optical fiber sensors, magneto strictive materials and cement-based intelligent composites, they all provide a new method for a long-term, real-time health monitoring of civil engineering structures (Tong et al., 2016). These intelligent material devices have sensing, or sensing and driving the dual function, and they are integrated with the civil structure to form an intelligent structural system. Such structural health detection system also includes the composition of signal processing, signal interpretation software and user interface. To achieve long-range detection, the signal transmission should also be considered (Yi et al., 2014).
Among the many intelligent materials, piezoelectric materials, which are mainly represented by piezoelectric ceramics, have the advantages of integrated sensing and driving integration making them suitable for structural health monitoring (Keulen, 2012; Zhu and Hao, 2012). At the same time, piezoelectric materials have fast response and good linear relationship, and most of piezoelectric materials have low energy consumption, low cost and easy processing. Therefore, the piezoelectric material working as the basic components, the development of a convenient and practical structural health monitoring system is also in line with China's current national conditions. Based on the above background, this paper is devoted to the research of piezoelectric ceramics using for structural health monitoring technology.

2. The detection principle of piezoelectric materials for the engineering structure

The method adopted is to make full use of the piezoelectric effect of piezoelectric ceramics, which can be used as the driver of transmitting signal or the sensor of receiving signal by arranging it at the key position or the designated position of the structure (Yang and Fritzen, 2012). When driving the piezo ceramic actuator by

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applying an excitation signal while recording the received signal from the sensor, the possible damage to the structure (especially the crack) can cause a change in the received signal (Figure1).

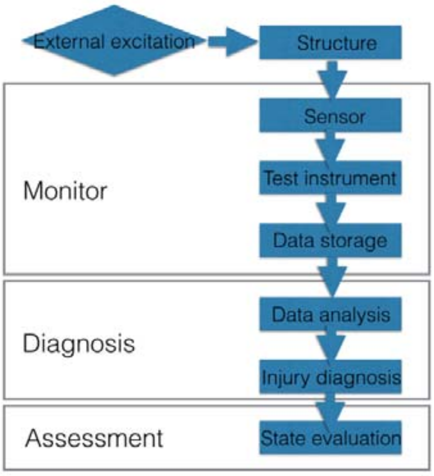

Figure 1: Structural health monitoring system

Using this principle, the piezoelectric ceramic sensor is arranged inside the structure, which is combined with identification algorithm, and can be timely and effective to infer the general location of the structural damage and the specific extent in order to achieve the true sense of the structural health monitoring. Therefore, it is of great technical and economic significance to conduct theoretical and practical research on the structural health monitoring using piezoelectric ceramics, so we can avoid the high maintenance cost and extend the service life of the structure. Piezoelectric ceramic materials in civil engineering structure health monitoring have the following advantages (Savin et al., 2014): (1) Piezoelectric ceramic materials are widely used in recent years, and they are the new intelligent materials. How to make good use of this new material will have an important impact on social development.

(2) The use of piezoelectric ceramics in the structural health monitoring provide a new idea for the development of a sensor sensitive, safe, reliable, and large measuring range of new sensors.

(3) The use of the characteristics of piezoelectric ceramics on the structure of buildings, and structures for health monitoring determine the location of structural damage to assess the extent of structural damage much better.

(4) The piezoelectric ceramic materials which are monitoring devices made of low-cost and reliable, can be widely used in the field of civil engineering, and can bring good economic benefits.

3. Piezoelectric ceramic sensor performance testing

3.1 Piezoelectric ceramic chip selection

Table 1 compares the basic properties of several strain-sensing materials. It can be seen that the response of piezoele

Ctric ceramics frequency range is the shape memory alloy and fiber-optic materials, which are twice the frequency response range; although the piezoelectric ceramic response frequency range (Shih et al., 2013). The field is smaller than the piezoelectric film, but the piezoelectric ceramic can respond to a minimum of 0.001 micro strain, i.e. the material has a corresponding. Change in the high sensitivity.

Table 1: Performance comparison of several smart sensing materials

Characteristic	Fiber	Memory alloy	Piezoelectric ceramics	Piezoelectric thin film
Cost	Medium	Poor	Medium	Poor
Maturity	Good	Good	Good	Good
Network	Y	Y	Y	Y
Embedding property	Good	Good	Good	Good
Linear degree	Excellent	Excellent	Excellent	Excellent
Response frequency	1~10000	1~10000	1~20000	1~50000
Sensitive frequency	0.1	0.1~1	0.001~0.1	2
Maximum strain	200	-	5000	200

Table 2 shows, for different applications, there are many types of piezoelectric ceramic materials to choose from. In order to structure the health
The P-5 type piezoelectric ceramics with good sensing and driving functions are selected in this paper.
Piezoelectric ceramics for concrete structure is monitoring. The piezoelectric ceramic has a high electromechanical coupling coefficient, a high dielectric constant and a high dielectric constant
Flexible characteristics, and thus in the drive and sensing areas have a good performance. Table 2 is used in this paper piezoelectric ceramic materials of the parameters.

Table 2: Parameters of the piezoelectric ceramic sensor used in this paper

Performance categories	Value	Performance categories	Value
Piezoelectric constant d33	449	Dielectric constant	1700
Piezoelectric constant d31	-195	Curie temperature	321
Piezoelectric constant d15	650	Coupling coefficient	0.77
Density	7600	Elastic compliance coefficient	1.76
Dielectric loss	0.02		

3.2 The combination mode between the piezoelectric ceramic and the main structure

At present, piezoelectric ceramics as the main sensor of the piezoelectric structure of health monitoring and damage diagnosis technology in the piezoelectric structures, the combination mode between the piezoelectric ceramic and the main structure has two main forms, that is, paste and embedded. In practice, choosing which combination of methods mainly depends on the main structure of the material characteristics and the use of damage diagnosis methods (Hu et al., 2013).
Paste type: Paste-type bonding method is to paste the piezoelectric ceramic sheet directly on the surface of the structure. First, the structure of the paste position should be polished smooth. Next, wipe structure paste position and piezoelectric ceramic sensor and structure contact surface dust, dirt with acetone. And then use the epoxy or 502 glue to paste the sensor in the structural surface. Paste to ensure that the sensor and colloid contact even and full, so that the force is with uniformity of the sensor and to avoid charge leakage. The advantages of the bonding method are easy to operate and the force of the piezoelectric ceramic sheet is relatively simple. However, the shortcomings of the combination are also more obvious. First of all, because of the piezoelectric material on the temperature and humidity are more sensitive to exposure to the natural environment of piezoelectric ceramics affected by changes in ambient temperature, humidity. It may give monitoring results with while civil engineering structures have a long service life, and structures are subject to external factors such as climate change, natural disasters, and human activities during service. Role, these factors will also be affixed to the knot. The surface of the piezoelectric ceramic sheet is damaged.
Embedded: Embedded in the way of the piezoelectric ceramic being embedded in the monitored structure. The combination is mainly applied to concrete structures. Its advantage is that it can weaken the influence of external environment such as temperature and humidity on the piezoelectric ceramic. And the structure of the main body can protect the piezoelectric ceramic, which can prolong the service life of the piezoelectric slice greatly, to ensure long-term effectiveness of the health monitoring process. These piezoelectric ceramic pieces wrapped with mortar blocks or fine stone concrete blocks called as "smart aggregate." Figure 2 shows the "smart aggregate" constitute a schematic diagram.

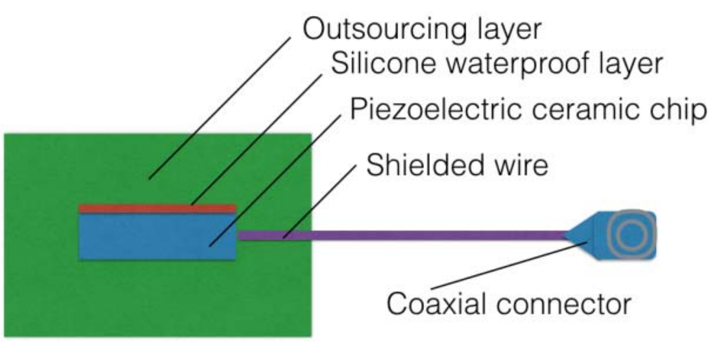

Figure 2: Schematic of smart aggregate composition

The piezoelectric ceramics used in the preparation of "Aggregate" is mainly in the form of thickness extensional vibration mode. The stress wave mode of the signal emission is dominated by longitudinal wave, which is made by BaoyingTianyi Super Energy Technology Co., Specifications, dimensions of the PZT-4 and PZT a 5-type piezoelectric ceramic.

3.3 Charge amplifier

Because of the piezoelectric ceramics are used as the high impedance component, its output current signal is very weak, which is generally carried out after the preamplifier signal acquisition (Masmoudi et al., 2013). According to the working principle of piezoelectric materials, the output signal can be charge, but also the voltage signal. The corresponding cases should be chosen in charge or voltage amplifier. Charge amplifier is a high source impedance charge piezoelectric element into a low impedance voltage source special preamplifier. Theoretical analysis shows that when the charge amplifier is under certain conditions, the sensitivity of the sensor has nothing to do with the length of the cable. In practical application, the composition of the piezoelectric sensor measurement circuit is shown in Figure 3.

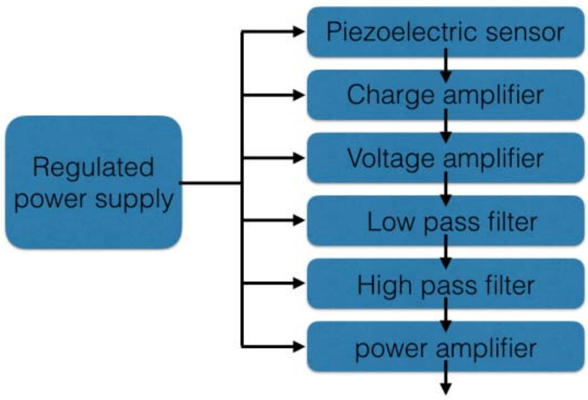

Figure 3: Piezoelectric sensor measurement circuit

In order to test the performance of the piezoelectric ceramic sensor after packaging and compare the performance of piezoelectric ceramic sensor of different thickness and different size, piezoelectric ceramics are used in this paper. Use multi-meter capacitance file and ohm file respectively on the sensor capacitance and resistance test. Welded wire, the measured capacitance of the finished package is also given. Due to the inconsistency of the wire length and the difference of the piezoelectric material, the measured capacitance value of the piezoelectric ceramic sensor has some differences. By the multi-meter of the measured after the sensor in the package are more than 10M0 resistances, to ensure the piezoelectric ceramic sensor insulation.

3.4 Sensor sensitivity test

The static sensitivity of the sensor is the ratio of the change of the response of the sensor under the static force with the corresponding input quantity (Part et al., 2013).
The sensitivity= the actual output / input
As the piezoelectric ceramic is a kind of charge source device, it can not be tested by static force. In addition, the method of dynamic calibration of piezoelectric sensor is more complex. In view of this, this paper uses the dynamic loading test method to test the sensitivity of the sensor. In the process the frequency of 1 Hz sine wave signal control MTS is selected. The sensor in the measurement range is of the step size of 100N, loading 1.2kN. The actuating device output stability to ensure security, each cycle is with five amplitude cycle.
The peak value of the output signal of the sensor under cyclic load is taken as the output of the piezoelectric sensor, and the relationship between the output and the load is investigated.
The gain of the charge amplifier is 10. It can be seen that the output of the sensor has a good linear relationship with the load curve of each load

3.5 Experimental study and output voltage characteristics analysis

Piezoelectric ceramic sensor as a piezoelectric intelligent concrete structure of the core components, the performance of the sensor directly impact the results of structural health supervision measurement and damage detection. The study of the related performance of piezoelectric ceramic sensors, such as the frequency independence, linearity, sensitivity and stability of the sensor, has been studied in detail. Based on the positive piezoelectric effect of piezoelectric materials, the piezoelectric ceramic sensor has a good performance, and it has laid a good foundation for the passive monitoring of piezo ceramic sensors. However, the whole system is composed of the piezoelectric ceramic signal driver, the piezoelectric ceramic signal receiver, the concrete specimen and the test equipment, which is based on the active health monitoring and damage diagnosis technology of the concrete structure of the piezoelectric ceramic sensor. Health monitoring and damage diagnosis process involves not only the positive piezoelectric effect, but also the inverse piezoelectric effect (Yu et al., 2013). The stability of the test equipment which is used to test the smooth plays a crucial role. So it is necessary to study the relative performance of the whole system and lay the foundation for the next model test.

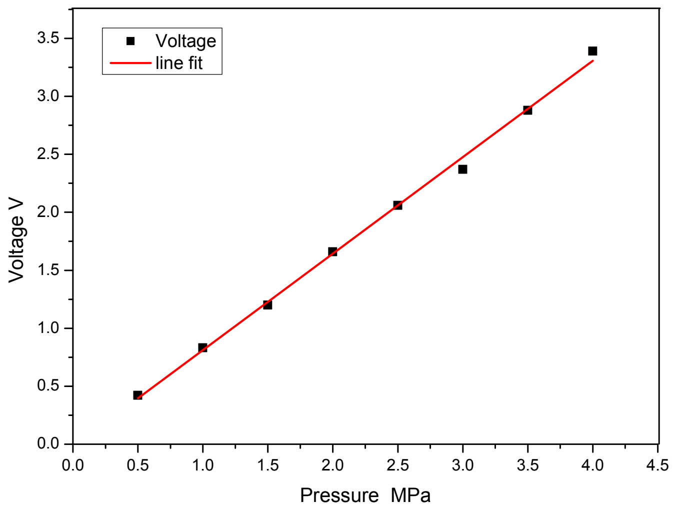

Figure 4: Output verses load

It can be seen from the curve in Figure 4 that the output of the piezoelectric ceramic sensor exhibits a good linear growth relationship with the loading curve of each load.

Table 3: Specific parameters of piezoelectric ceramic chip and its sensitivity values

Number	Size	Theoretical capacitance	Actual capacitance value	Sensitivity
Senor 1	0.3*10*10	5.014nF	4.15nF	0.334
Senor 2	0.5*10*10	3.009nF	3.49nF	0.398

It can be seen from the test results of the sensor sensitivity in Table 3 that the sensitivity of the piezoelectric ceramic sensor with the same area and different thickness has a tendency to increase with the increase of the thickness.

4. Conclusion

According to the characteristics of piezoelectric ceramics, this paper develops a piezoelectric ceramic sensor with cement paste. The sensor has the advantages of simple process, small volume, convenient installation, good dynamic performance and large amplitude of output signal. It is suitable for passive monitoring of civil engineering structure. With the cement paste, the piezoelectric ceramic sensor has good phase with the concrete structure. To avoid the metal-encapsulated sensor susceptible to corrosion deficiencies, the dynamic mechanical properties of the sensor test results can be seen that each sensor output are showing a good linear relationship.

For the same size sensor, its sensitivity with the internal package of piezoelectric ceramic Size changes, that is, the greater the area of piezoelectric ceramics, the higher the sensitivity. For the same area, the thickness of different piezoelectric ceramics, the sensitivity of the sensor after packaging changes little. A slight decrease in the thickness of the trend. For the same size, different shapes of the sensor, the pressure side of the sensor for the square of the highest sensitivity.

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