Performance-based Piezoelectric Material Applied in Health Inspection of Civil Engineering Structures

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Abstract. The application of piezoelectric impedance principle in health monitoring of civil engineering structures has attracted more and more attention. In this paper, the application of piezoelectric materials in health detection of civil engineering structures is reviewed. The basic principles, research progress, advantages and problems of impedance method and wave method are analyzed. Civil engineering structures, such as dams, bridges, high-rise buildings, etc., will inevitably suffer some damage during their service. Sometimes it is caused by natural factors of force majeure, or due to long-term accumulation damage, these damages will directly cause structural resistance to decay, and in severe cases may lead to catastrophic accidents. The support role of structural monitoring technology is needed to provide early warning of these disasters. Piezoelectric materials, piezoelectric impedance principles, interaction models of piezoelectric materials with monitored structures, and monitoring techniques based on impedance information. The research results of piezoelectric material size selection, scanning frequency selection, sensing range, binder influence, data acquisition equipment development and data processing methods are summarized.

1. Introduction
Structural health detection technology is to judge the specific location and degree of damage of civil engineering structures by the sound basis obtained and comprehensive analysis based on the overall characteristics. Civil engineering structures generally have a long service life and are difficult to replace once constructed [1]. However, the performance of any civil structure will deteriorate over time, mainly due to the aging of the material itself, overuse, overload, environmental erosion, lack of maintenance and testing means to meet the requirements. Effective civil engineering structural health detection system can diagnose the location and degree of defects (cracks, rusts, etc.) in real time, so that the structure can be repaired and strengthened in time to ensure the integrity and safety of the structure [2]. At present, many structural health detection methods are applied to various civil engineering structures or their components. Therefore, in the process of civil engineering use, it is necessary to regularly test it, using effective testing methods, not only can increase the quality of the test results, and timely find problems in civil engineering [3]. Quickly repair it, reduce its security risks, and at the same time reduce the detection time and improve the efficiency of detection. Therefore, it is of great significance to strengthen the practical application of piezoelectric materials in the health testing of civil engineering...
structures [4]. In theory, the advantage is that the external factors that generate vibration can be used as the excitation source. The process of damage detection does not affect the normal use of the structure, and the detection and identification of structural damage can be conveniently performed. However, global damage identification is not sensitive to local damage, and is susceptible to environmental temperature and boundary conditions, which is difficult in practical engineering applications [5].

Civil engineering structures are generally used for a long period of time and are difficult to replace once built. However, the performance of any civil structure will deteriorate with time, which is mainly due to the aging of the material itself, overuse, overload, environmental erosion, lack of maintenance and detection methods are difficult to meet the requirements [6]. An effective civil engineering structural health inspection system can diagnose the location and extent of defects (cracks, rust, etc.) in real time, so that the structure can be repaired and strengthened in time to ensure structural integrity and safety. At present, many structural health detection methods are applied to various civil engineering structures or their components [7]. Structural health detection technology is suitable for monitoring all kinds of structures, especially for civil engineering, for civil engineering structures. Structural monitoring technology can detect real-time damage of structures under severe damage or disaster. Damage of monitoring structures under long-term considered damage or changes of the whole environment [8]. However, in the construction of civil engineering, no matter how high the quality is, with the passage of time, under the influence of various factors, it will have a corresponding impact, causing certain damage to its internal structure and increasing the hidden dangers of civil engineering.

2. Piezoelectric effect of piezoelectric materials and common types of piezoelectric materials

2.1 Physical model of piezoelectric effect

An important characteristic of piezoelectric materials used in structural health monitoring is their piezoelectric effect. The piezoelectric effect was first found on crystals. The physical mechanism of piezoelectric effect was explained by taking crystals as models. Structural health monitoring technology has been applied abroad for a long time and a wide range. In addition to its application in bridges, it is also widely used in high-rise buildings and other fields in the new era [9]. Impedance method is a typical application of electromechanical coupling effect of piezoelectric materials in structural diagnosis. Its basic principle is that the mechanical impedance changes due to structural damage, but it is difficult to obtain the mechanical impedance of the structure through direct testing. The impedance method utilizes the electromechanical coupling effect of the piezoelectric material. When an alternating electric field is applied to the piezoelectric sheet bonded to the structure, the piezoelectric sheet and the structural body generate mechanical vibration [10]. The impedance method utilizes the electromechanical coupling effect of the piezoelectric material, and when an alternating electric field is applied to the piezoelectric sheet bonded to the structure, the piezoelectric sheet and the structural body generate mechanical vibration. This mechanical vibration produces an electrical response in the piezoelectric sheet by the inverse piezoelectric effect, which is manifested as a change in the electrical impedance of the piezoelectric sheet. By comparing the AC impedance spectrum of the piezoelectric sheet with the structure without defects, the damage inside the structure can be diagnosed. Table 1 lists some of the major piezoelectric materials and their properties. It can be seen from Table 1 that piezoelectric materials can be classified into inorganic and organic (polymer) piezoelectric materials.

| Material name                        | Transition temperature℃ |
|--------------------------------------|-------------------------|
| Shi Ying single crystal              | 500                     |
| Polyvinylidene fluoride              | 15                      |
| Lead zirconate titanate 52/48        | 359                     |
| Lanthanum-doped lead zirconate titanate 8/65/35 | 56                     |
| barium titanate                      | 152                     |
| Lead niobate                         | 581                     |
2.2 Common types of piezoelectric materials

Piezoelectric materials can be divided into three categories: First, piezoelectric crystals, including piezoelectric quartz crystals and other piezoelectric single crystals. The second is piezoelectric ceramics; the third is new piezoelectric materials, including piezoelectric semiconductors and organic polymer piezoelectric materials. The application of infrared thermal image monitoring technology is relatively systematic, using the principle of infrared thermal imaging, and applying infrared thermal imaging technology to detect the overall release hotline of the detected engineering structure or object. Thus forming a thermal image, not only can directly reflect the content of the material, but also can monitor many defects and problems according to the state of the structure and structure. However, the current impedance method is only a qualitative detection method. This is because many factors, such as cracks, corrosion, holes, etc., will change the mechanical impedance of the structure, and it is also very difficult to identify the types of defects, damage degree, etc. In a word, the advantages of impedance method are: (1) the adopted working frequency is relatively high (30 khz ~ 500 khz, i.e. the driving electric field frequency of the piezoelectric sheet), so its sensitive range is limited to the area near the piezoelectric sheet, thus acting in a far field. Such as changes in load, stiffness and boundary conditions, will be isolated so that the failure location can be accurately identified. (2) A piezoelectric chip is both a sensor and a driver. The idea of self-induction driver is applied to reduce the number of piezoelectric chips in the structure detection system. (3) It does not rely on model analysis, does not need to master the background knowledge about the structure, and the output signal is easy to explain.

Single crystals with piezoelectricity are collectively referred to as piezoelectric crystals, which include lithium salts and ferroelectric single crystals in addition to natural and artificial Shi Ying crystals. In order to better understand the impedance method detection, impedance method detection has been carried out for different civil engineering. Firstly, the brick wall is inspected, and five different positions are selected in different parts of the brick wall to paste PZT patches. The change of mechanical impedance of brick wall in different stages is detected, and whether cracks appear in brick wall can be judged according to the detection result of mechanical impedance. The greatest advantage of infrared thermal image monitoring technology is that it does not need to directly contact with the detected objects. It is arbitrary in the overall technology. It can be used up and down, left and right, and can scan the detected objects at any time and anywhere. Infrared thermal image monitoring technology is suitable for non-contact, wide range of non-destructive detection. Another important feature is that it can be monitored during the day and at night without choosing time. It has good complementarity to the function and effect of the existing NDT technology. This technology has been applied freely and extensively, and has made great achievements abroad. In addition to natural piezoelectric crystals, polycrystalline materials with piezoelectric properties can also be synthesized artificially by mixing ingredients and sintering at high temperature. After solid-state reaction between powders, polycrystals are irregularly assembled to form piezoelectric materials, commonly known as piezoceramics.

3. Application of Structural Health Monitoring Technology in Civil Engineering

3.1 Application of Resistance Strain Gauge Method

The application of resistance strain gauge method is also a monitoring method which has been rising in recent years. This method has some limitations compared with infrared thermal image monitoring technology, but it has its own great advantages. For example, the resistance strain gauge method is suitable for short-term monitoring, and its price is also very low. It can save cost to a great extent, ensure financial budget, and its use method is relatively simple and easy to operate. Lead zirconate titanate piezoelectric ceramics (PZT) is one of the most common materials used in structural health monitoring. It has the characteristics of strong piezoelectricity, high dielectric constant, simple manufacture and low cost, but it also has the shortcomings of brittle material and unsuitable surface. The wave method can detect larger areas than the impedance method, and can extract more kinds of signals to diagnose the structural integrity. The wave method is the same as the impedance method. It is an active detection
method that directly activates the structure through the set driver. However, the current impedance method is only a qualitative detection method. This is because many factors, such as cracks, rust, holes, etc., can change the mechanical impedance of the structure, and it is difficult to identify the type of damage and the degree of damage.

Modal parameters are seismic and wind resistant in high-rise buildings. One of the most important design parameters in research such as health monitoring and injury diagnosis. However, the high-rise building is huge in volume, and it is difficult to use the conventional modal analysis method to obtain the excitation and response signals to effectively estimate the modal parameters of the system. Figure 1 is a time-domain waveform diagram of the top-level vibration response obtained under ambient excitation. Figure 2 is a free decay signal obtained from vibration response data using a random decrement method.

Fig. 1 Vibration response time domain waveform

Fig. 2 Free attenuation response time domain waveform
New piezoelectric materials include piezoelectric semiconductors and organic polymer piezoelectric materials. Piezoelectric semiconductors have both piezoelectricity and semiconductor characteristics. China's economy is developing rapidly and science and technology are being updated day by day. The constant application of this strain gauge method will be more extensive and its advantages and advantages will be better brought into play. I believe it will be more solid in future applications and more convenient to use application strategies. Passive detection is mainly aimed at equipment with certain vibration amplitude. At this time, PZT is used as a sensor. It is only necessary to stick PZT on the surface of the equipment or embed it into the equipment to sense the vibration of the equipment so as to judge whether the equipment is damaged. Passive detection can be used for damage detection of rotating machinery such as engines and steam turbines. Like active detection, passive detection methods include charge method and impedance method, which are not described in detail here. In this detection method, piezoelectric patches can not only be used as sensors, but also as actuators. In the process of detection, according to the principle of self-induction actuators, the detection system will be simplified to reduce the number of piezoelectric patches used. Finally, when using this method to inspect civil engineering, it is enough to inspect and calculate civil engineering directly without establishing corresponding models and understanding the relevant knowledge of civil engineering structure, which makes the inspection more simple and convenient.

3.2 Application of Ultrasound Detection Method
The unique advantages of organic polymer piezoelectric materials are lightweight, soft and high tensile strength. They can be used as sensors or as exciters. For example, PVDF materials made of synthetic polymer after stretching and polarization treatment. To detect and analyze the specific situation of ultrasonic wave propagation in the structure, such as the propagation speed, frequency, the degree of receiving signal, and integrate the detected data organically. Observing its regularity and change, we can finally form a judgment, that is, concrete defects. Our country has innovated the ultrasonic method according to its own characteristics, allowing the ultrasonic method to penetrate far distances and is very safe and convenient. In order to enable relevant personnel to have a deeper understanding of the fluctuation detection method and to better apply it in the subsequent tests, this paper has made some research on the practical application of some previous fluctuation detection methods. At the present stage, in order to increase the convenience of traffic, some suspension bridges will be built on many rivers. In suspension bridges, steel cables play a weighing role. If problems occur in the steel cables in the suspension bridges, the potential safety hazards of the suspension bridges will be increased. However, this method has certain limitations at present, which limits the distance and range of detection, and the detection result is not intuitive enough. It can be judged only after many ultrasonic tests are performed, which may affect the detection result. Therefore, our country should pay more attention to the improvement and reform in this area.

Moire method is also a newly arisen structural health monitoring method in recent years. The overall operation process is relatively complicated, but a relatively complete conclusion can be obtained. The basic principle of piezoelectric impedance technology in the application of structural damage diagnosis and monitoring is that after the piezoelectric element is adhered to the surface of the structure or buried in the structure, the piezoelectric element is excited by applying high frequency AC voltage, and the impedance function of the coupled structure is obtained by impedance analysis method. According to the impedance spectrum change of the coupled structure, the damage condition of the structure can be indirectly judged. Moire method and shadow moire method are two main methods about civil engineering which can be used in structural health monitoring technology. However, the application conditions are more harsh. We should improve them from the technical point of view and find a better direction and connotation. The application conditions of moire method are improved to ensure the value of structural health monitoring in the future. In the test results, it can be found that there is a significant difference between the test results at the place where the mass block is placed and that at the place where the mass block is not placed. However, there is no significant difference between the detection
results of other places and the monitoring structures without mass blocks, which can effectively detect the failure of concrete beam structures.

4. Conclusion
The application of piezoelectric materials in civil engineering health detection is mainly based on impedance method and wave method. The former diagnoses defects by the relationship between piezoelectric materials' impedance and structural mechanical impedance, while the latter diagnoses defects by the scattering of acoustic/ultrasonic stress waves in structures. Structural health monitoring technology of civil engineering is a new industry, and its research and development in China is still in its infancy. There are still many problems in research methods. Therefore, in the future development process, the structure monitoring technology of civil engineering should be more perfect, keep pace with the times, put forward different solutions according to different problems, and choose the best one to ensure the stability and stability of civil engineering. If the vibration identification method is used, the excitation of large civil structures will be very difficult. Problems to be studied include: geometric parameters of the piezoelectric sheet, thickness of the bonding layer, input signals, and optimization of the distributed sensing system. Long-term durability and performance stability of piezoelectric sheets in civil structures. And advanced data processing and defect identification methods. The health monitoring of civil engineering structures often requires many piezoelectric sensing elements to be affixed or buried inside the structure. However, current theoretical and experimental research is only for one or a small number of piezoelectric sensing elements.

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