Theoretical and Experimental Study on Mechanical Model of Piezoelectric Ceramic Sensor

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Abstract: Among the piezoelectric intelligent materials, piezoelectric ceramic is a representative material, whose advantages are embodied in the integration of sensor and driver. The sensor has the function of PZT sensor, which is mainly used in structure detection and health monitoring. The sensor can not only respond quickly, but also has a good linear relationship, with low energy consumption and low consumption components. It is very easy to process and shape it. However, in the specific application summary, especially in the monitoring of concrete structure, due to the complex boundary conditions of PZT sensor itself, the stress situation is also very complex, so the theoretical analysis of PZT sensor is difficult to achieve high accuracy. It is generally believed that there is a close relationship between the pressure of PZT sensor and the output voltage, but other factors, such as rubber layer, are not recognized. In view of the gap between the current piezoelectric ceramic sensor research and the actual. This paper focuses on the mechanical model theory and experiment of piezoelectric ceramic sensor.

1. Introduction

As an intelligent material, piezoelectric ceramic has the advantages of simple operation procedure, good adaptability to environmental temperature and humidity, moisture resistance, and normal use in high temperature environment. However, under the action of external force, piezoelectric ceramic will deform and generate potential. If voltage is applied to piezoelectric ceramic, it will deform. Therefore, piezoelectric ceramic It is mainly used for sensing element and driving element. Therefore, piezoelectric ceramics are widely used. In this paper, the mechanical model is used to study the piezoelectric ceramic sensor, which vibrates under the action of sinusoidal load. The correctness of the sensor model is verified by analyzing the electrical signal transmitted by the sensor and monitoring the real-time state.

2. Basic Properties of Piezoelectric Ceramics

As a detection device, the sensor can sense the measured information and convert the electrical signal into the specified signal according to the law. The sensor can transmit information, display the information, and also store and control the information. The structure can be automatically detected and controlled by the sensor. The sensor has a sensitive element that can directly detect the measured element. In addition, there is a conversion element used for electrical signal conversion, that is, the transmitter.

The sensor has static and dynamic characteristics. The static characteristic of the sensor is to transmit static input signal and output signal. Because the static signal has no direct correlation with time, it takes the input signal as an independent variable, and the dependent variable is the corresponding output.

The dynamic characteristic of the sensor is the characteristic of the corresponding output value when the input value changes. The experiment shows that the control of the input signal is very easy and the solution is relatively easy, and the response of the sensor to any input signal is related, so

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the response of any input signal can be figured out through the response of the standard input.

In the operation of piezoelectric sensor, the main factors that affect its accuracy are temperature and noise. With the change of environmental humidity, the performance of piezoelectric sensor will be affected. If the sensor operates in the environment with high temperature and humidity, the insulation resistance will be reduced, and the low-frequency response will be affected and deteriorated. The target of piezoelectric sensor is 1014 ohm, which requires a reasonable design of structure, a sealed whole of quantity conversion elements to ensure good insulation, and a complete sealing of both ends of the cable by welding. The piezoelectric sensor is affected by noise. The piezoelectric sensor is capacitive. When the static charge can not disappear quickly, but is transmitted to the amplifier, it will lead to noise and have a bad impact on the cable. In order to avoid this phenomenon, it is necessary to tighten the cable to avoid relative motion. In addition, there are many kinds of measuring instruments installed in the test system. If there is potential difference between the grounding point of each instrument and the grounding point of sensor, there will be noise. In order to solve the noise, it is necessary to implement the grounding of the measurement system to a point, and set the grounding point at the input end of the indicator [1].

3. Mechanical Model

In the derivation of piezoelectric ceramics, the vibration equivalent model is used. Piezoelectric ceramics are regarded as an ideal elastomer, and the influence of loss factor, temperature factor and self-induced electric field factor are ignored. Before the derivation of the pressure equation, it is necessary to assume the piezoelectric ceramic structure in the single piezoelectric ceramic sheet and erect the piezoelectric ceramic structure embedded in the concrete.

The piezoelectric ceramic sheet is regarded as an ideal dielectric material, in which there is no free movement of electric charge. All the same-sex materials are elastic base materials. The piezoelectric sensor is bonded on the base material with adhesive, the thickness should meet the requirements, the bonding should be perfect, and the problem of "leakage" cannot be caused.

Because the diameter of the piezoelectric ceramic disc is 20 times more than its thickness, it can be set as a thin disc structure. The radial pressure is much lower than the axial upward pressure. When deriving the piezoelectric equation, it is regarded as a uniaxial stress

3.1. The Electrode Surface of Piezoelectric Ceramics is Equipotential Surface, and the Electric Field Between Positive and Negative Electrode Surfaces Is Uniform

When the piezoelectric ceramics are embedded in the concrete and clamped by the concrete materials above and below, the radial vibration amplitude will be far greater than the axial vibration amplitude under the action of the compressive stress. At this time, the displacement can be set as "0" or as a constant value.

3.2. Piezoelectric Equation and Vibration Equation

When the PZT sheet is regarded as a sensor, the vibration of the elastomer is set to proceed along the axial direction. The electric field and polarization are in the same direction. At this time, the PZT will produce expansion deformation and change along the thickness direction. Then the surface charge output can be seen, which is represented by a mechanical model, as shown in Figure 1. (Figure 1: PZT mechanical model)

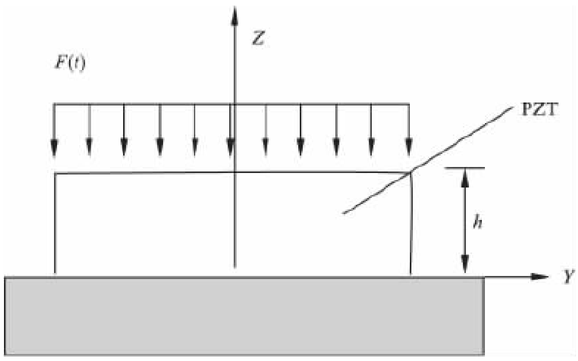

Figure 1 Mechanical model of PZT

PZT sheet is pasted on the surface of the structure. The contact surface between the free end and the structure is electrical short circuit. The piezoelectric equation is adopted as follows.

$$S_i = s_{ij}^E T_j E_j + d_{ni} E_n$$
$$D_m = d_m T_j + \varepsilon_{mn}^T E_n \qquad (1)$$

Since only the vibration in the thickness direction is considered, the piezoelectric equation can be simplified as follows:

$$S_3 = s_{33}^E T_3 + d_{33} E_3 (a)$$
$$D_3 = d_{33} T_3 + \varepsilon_{33}^T E_3 (b) \qquad (2)$$

In this formula, S_3 is the strain produced by PZT; d_{33} is the piezoelectric strain constant; s_{33}^E is the short-circuit elastic compliance constant; T_3 is the PZT stress; ε_{33}^T is the free dielectric constant; D_3 is the potential shift, E_3 is the electric field strength, and the second-order effect is ignored, that is, the influence produced by the self induced electric field does not need to be considered.

You can get it:

$$D_3 = d_{33} T_3 \qquad (3)$$

Therefore, the charge Q output from the piezoelectric ceramic sheet is:

$$Q = \iint D_3 dxdy = Ad_{33} T_3 = CU \qquad (4)$$

Capacitance is:

$$C_a = \frac{\varepsilon_0 \varepsilon_1 A}{h} \qquad (5)$$

In this formula, ε_0 is the dielectric constant of air, which is 8.86 × 10-12f / M; a is the area of pat; ε_0 is the relative dielectric constant of pat; h is the thickness of Pat.

After the PZT sheet is pasted on the surface of the structure, under the action of simple harmonic load, the PZT sheet will vibrate and run along the z-axis direction. See Figure 2 for the simplified model. (Figure 2: schematic diagram of PZT mechanical model)

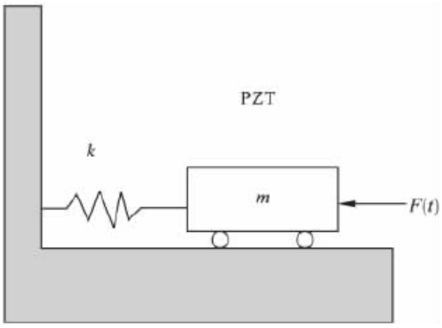

Figure 2 Schematic diagram of PZT mechanical model

The vibration equation is:

$$mx + kx = F_0 \sin wt \tag{6}$$

Get:

$$x(t) = \frac{F_0 e^{iwt}}{m(w_n^w - w^2)} \tag{7}$$

So, PZT voltage is:

$$U(t) = \frac{d_{33} hkx^*}{\varepsilon_r \varepsilon_0 A} = \frac{d_{33} hF_0 e^{iwt}}{\varepsilon_r \varepsilon_0 Am(w_n^2 - w^2)} = \frac{d_{33} hT_3(t) e^{iwt}}{\varepsilon_r \varepsilon_0 (1 - \frac{w^2}{w_n^2})} \tag{8}$$

In the formula, WN is the natural frequency of PZT.

4. Experimental Verification

The piezoelectric ceramic is pasted on the surface of the aluminum sheet, and the sinusoidal load excitation is applied to the piezoelectric ceramic by the pressure ceramic driver. When the piezoelectric ceramic receives the signal, the oscilloscope can extract the data from the signal and read it out.

During the experiment, if the amplitude of the alternating voltage driver is 10V, there will be stress. At this time, the stress wave will take effect. On the PZT chip with a diameter of 20 mm, the wave band can be intercepted by an oscilloscope and filtered to obtain the voltage curve. See Figure 3 and Figure 4 for details. (Figure 3: voltage output curve before filter under driver action; Figure 4: voltage output curve after filter under driver action)

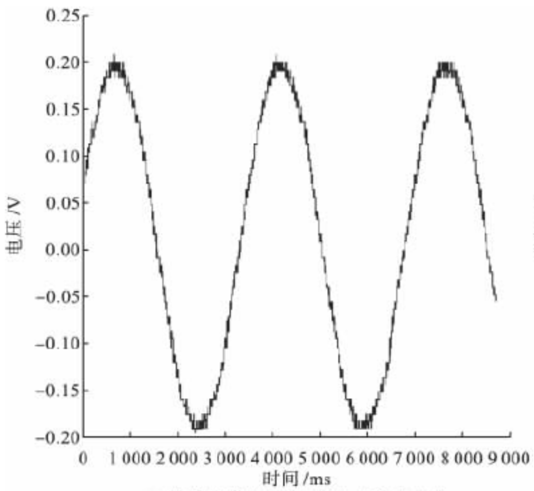

Figure 3 Voltage output curve before filtering under the action of driver

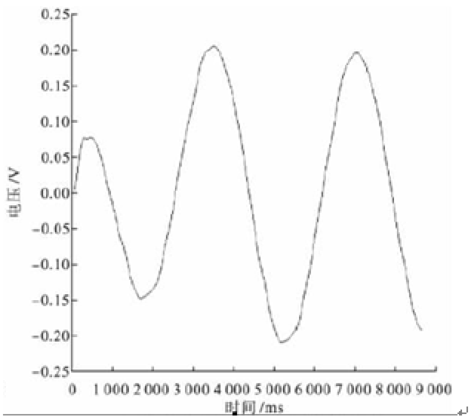

Figure 4 Voltage output curve after filtering under the action of driver

Through the interpretation of Figure 3, it can be clear that before filtering, the voltage amplitude is 0.4148v, and through the interpretation of Figure 4, it can be clear that after filtering, the voltage amplitude is 0.408v. Through comparison, it can be clear that the mechanical model established is relatively reasonable.

The driving voltage is set as 1V, 2V, 10V, 20V and 80V, and the driving frequency of 100Hz is set. During the operation of the sensor, the voltage output curve is shown in Figure 4. (Figure 4: voltage output at 100 Hz drive frequency)

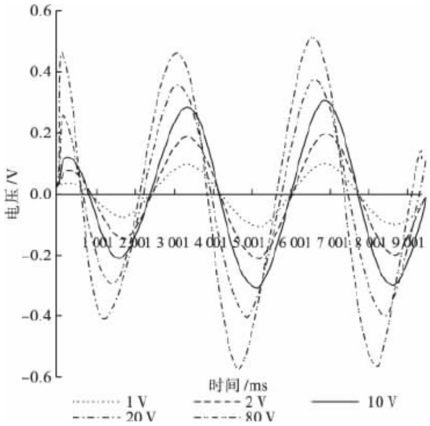

Figure 4 Voltage output at 100 Hz drive frequency

Through the interpretation of the curve, it can be clear that if PZT has a high sensitivity of voltage output under the action of relatively large stress, it can be clear through verification that during the operation of PZT sensor, there is a correlation between the value of voltage output and the force, and the curve change rule is shown in Figure 5. (Figure 5: relationship between output voltage and input stress assignment of PZT)

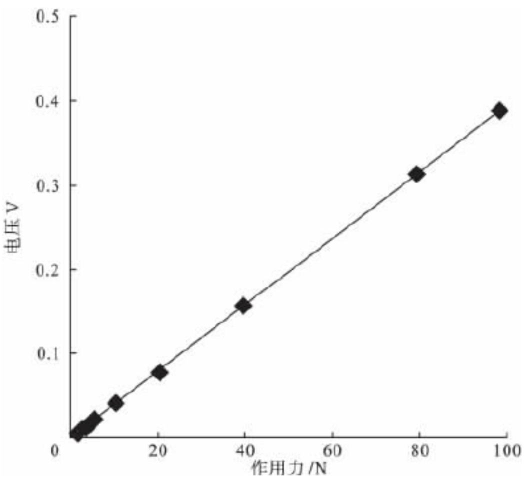

Figure 5 Relationship between output voltage and input stress assignment of PZT

In the process of verifying the gauge effect of PZT chip, when the voltage frequency is 10 V amplitude and 3000 Hz frequency, it is clear that under the same conditions, as the area of PZT chip increases, it is easier to collect signals when the voltage output value is Nobel. If there is concrete, part of the energy will be absorbed by the concrete, and the effect will be reduced correspondingly. According to the mechanical model established by the voltage equation and the vibration equation and through the test, it can be clear that it will produce 12.18% error, which is feasible to apply in the project.

5. Conclusion

Through the above research, it can be clear that the output voltage of piezoelectric ceramic sensor has a positive correlation with the force. When the output voltage increases, the force will increase, on the contrary, the force will decrease. If the stress effect of piezoelectric ceramic sensor is very large, the sensitivity of voltage output value will be improved, which is in accordance with the theoretical calculation. When the driving conditions are the same, the output voltage will be increased when the area of piezoelectric ceramic sensor is enlarged, and it is easier to collect signals. It is better to select PZT film with large specification in specific application.

References

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