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In-Situ Calibration of Piezoelectric Accelerometer with Built-in Exciting Component

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Abstract:

Piezoelectric accelerometer is widely used for monitoring the health states of machineries and structures. The validity, reliability and tractability of their measuring results should be verified by periodic calibrations or checks. But in some important vibration monitoring situation, it is impossible to check the accelerometer by normal comparison calibration method. So, a kind of piezoelectric accelerometer with built-in exciting component bad been developed to realize in-situ check purpose. The built-in exiting component is excited by an electric signal to vibrate the seismic mas and sensing piezoelectric component to simulate the vibration measured. The relationship of output and input electric signal of the accelerometer can be used to evaluate its performance. But previously this method was not traced to the vibration meteorology method and standard, the validity and reliability of this kind of accelerometer and the in-situ check method were not proved and supported. In order to establish tractability chain for this kind of accelerometer, its sensitivity was calibrated by vibration measurement standard, its electric sensitivity was a calibrated voltage measuring instrumentation and its coefficient of built-in exciting component is calculated, the electric exciting calibration method is linked to the vibration measurement standard. The modeling analysis and experiments reveal the tractability of the electric exciting calibration method and feasibility of the in-situ calibration based on this method.

***Keywords**: Accelerometer, Accelerometer with built-in exciting component, Calibration, In-situ calibration, Sensitivity.*

I. INTRODUCTION

Piezoelectric accelerometer are widely used for measuring the vibration parameters of machineries and structures for health monitoring purpose in the fields of power generation, automotive, aerospace, etc.[1-3] The purpose of calibration of accelerometer is to guarantee the accuracy of its sensitivity and thus the validity, reliability and tractability of the measurement of vibration parameters.[4] According to the calibration environment, vibration calibration can be divided into laboratory calibration and field calibration.[5] Normally the accelerometer should be periodically calibrated in a vibration calibration laboratory using methods such as laser interferometry, earth gravity, etc.[6-8] Although these methods have high calibration accuracy, they require precise equipment, high cost and operation requirements, and have problems such as cumbersome inspection process, time-consuming and labor-intensive, etc.

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Therefore, there is a large demand for the research on field calibration methods and related devices, which is a research hotpot in the field of vibration calibration.

At present, field calibration is mainly studied from two aspects: device and technical method. American Modalshop and MB companies were developing air-bearing-oriented low-frequency vibration calibration device. Domestic Gang Zhu and others also conducted research on portable vibration calibration system for field service.[9] These devices are currently only suitable for low and medium frequencies and require dis-assembly of the sensor to complete the calibration. In order not to disassemble the sensor and meet the requirements of in-situ calibration, requiring to change the structure of the sensor and study the method of in-situ calibration. Flanagan proposed a method to monitor the change of sensitivity and installation conditions, the frequency response of the impedance of the external load capacitor is measured by electrically exciting the piezoelectric element for monitoring [10]. However, this method can only be used for fault detection, and the specific sensitivity cannot be obtained. Gong Liang designed a piezoelectric stack installed at the bottom of the accelerometer to provide vibration excitation in situ to complete self-calibration. However, due to the lengthening of the base, the available frequency band of the accelerometer is narrowed and the distortion degree increases. A piezoelectric accelerometer with built-in exciting element has been developed, but research on in-situ calibration methods has been slow.

In order to solve realize the in-situ calibration of sensitivity of piezoelectric accelerometer. A method is proposed which takes the piezoelectric accelerometer with built-in excitation element as the research object. The built-in exiting component is excited by an electric signal to vibrate the seismic mas and sensing piezoelectric component to simulate the vibration measured. The relationship of output and input electric signal of the accelerometer can be used to evaluate its performance. In this paper the modeling analysis and experiments reveal the in-situ calibration feasibility of piezoelectric accelerometer with built-in exacting component, the sensitivity amplitude calibration of the accelerometer from 20Hz to 10000Hz can be realized. This calibration method is of great significance to solve the practical application problems such as the difficulty in disassembling the accelerometer and the high calibration cost, and to promote the development and progress of the field calibration method of the accelerometer.

II. OPERATION PRINCIPLE

The structure of piezoelectric accelerometer with built-in exciting components is illustrated in Fig. 1. According to the way of the piezoelectric element is stressed, they can be divided into compression-type and shear-type accelerometer. Although the configurations are different, the measurement and in-situ calibration principles are similar. When the accelerometer works in the actual measurement state, the exciting piezoelectric component could be regarded as a part of the base or pillar, the seismic mass generates inertial force due to external vibration, due to the existence of the positive piezoelectric effect, the sensing piezoelectric component would measure the inertia force and convert it to a charge output. When the accelerometer works in calibration state, the exciting piezoelectric component should be excited by an exciting electricity signal, due to the existence of the inverse piezoelectric effect, it produces a stimulative acceleration to the sensing piezoelectric component and seismic mass. Therefore, it can be seen

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that the exciting piezoelectric component is used to produce the equivalent piezoelectric driving force to simulate inertia force of the actual measurement environment.

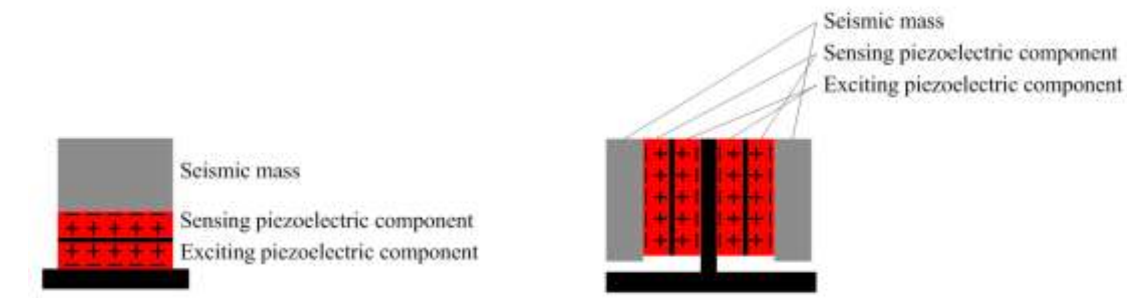

Fig 1. Configurations of compressing and shear piezoelectric accelerometer with built-in exciting components.

Based on the piezoelectric accelerometer, the typical monitoring system application is illustrated in Fig. 2. The signal generator is used to output the sinusoidal voltage (*Ue*) of a certain frequency and amplitude to the exciting piezoelectric component. The sensing piezoelectric component output charge signal is converted into electric signal (*E*) through the charge amplifier. The signal acquisition system is used to acquire and process electric signal (*E*) and (*Ue*). Vibration excitation (*X*) is generated by the shaking table.

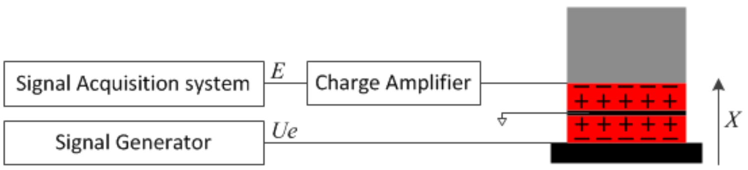

Fig 2. The typical measurement configuration based on piezoelectric accelerometer with built-in exciting component.

The sensitivity of the accelerometer with built-in exciting component is:

$$S_v = \frac{E}{X} \tag{1}$$

The electric sensitivity of the accelerometer with built-in exciting component is:

$$S = \frac{E}{U_e} \tag{2}$$

The self-calibration coefficient(c) represents the relationship between sensitivity and electrical sensitivity, which essentially reflects the internal structural characteristics of the accelerometer. According

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to formula (1) and (2), the coefficient of built-in exciting component is:

$$c = \frac{S}{S_v} \tag{3}$$

When performing in-situ calibration, calibration of sensitivity can be accomplished using known self-calibration coefficients and measuring electrical sensitivity:

$$S_v = \frac{S}{c} \tag{4}$$

According to formula above, it can be revealed that the electric sensitivity could be affected by the sensing part and exciting part of the accelerometer with built-in exciting component, the whole performance of the accelerometer can be reflected by the electric sensitivity. According to formula (2), the calibration of electric sensitivity only depends on the input and output electric signal, so in-situ calibration of the electric sensitivity is possible and feasible. In addition, it is necessary to pay attention to the self-calibration coefficient, which is measured in the laboratory in advance.

III. CALIBRATION PROCEDURE

Calibration of the piezoelectric accelerometer with built-in exciting component includes two parts: calibration in laboratory and in-situ calibration.

1. Before the accelerometer is installed in situ, in laboratory, as shown in Fig. 3, the sensitivity can be calibrated by primary or comparison methods [3-4], the electric sensitivity can be calibrated by a signal generator and a voltage measuring instrumentation, the coefficient of built-in exciting component can be calculated according to formula (3). The principle is shown in Fig. 4, the specific steps are as follows:

Fig 3. The sensitivity of the piezoelectric accelerometer was calibrated by comparison method.

(a1) In the frequency range of 20~10kHz, the signal generator outputs each fixed reference frequency of 1/3 octave, and the amplitude of the excitation signal is adjusted so that the output vibration signal size

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is $1m/s^2$.

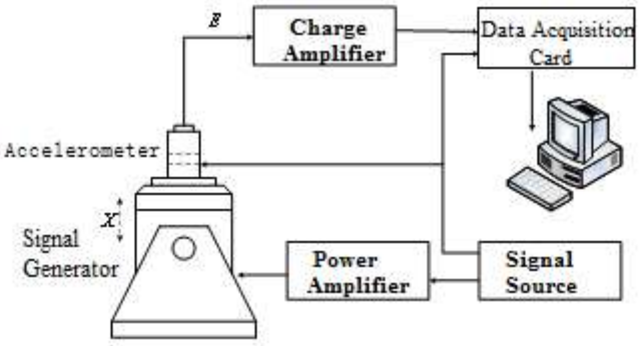

Fig 4. Built-in exciting element accelerometer laboratory calibration system

(a2) The output of the signal source excites the vibration table through the power amplifier, the accelerometer senses the external vibration signal to output the electric charge, uses the charge amplifier to obtain the output voltage, and uses the data acquisition card to collect the voltage signal. The sensitivity parameters of each reference frequency point accelerometer are determined by laser interferometric absolute calibration or comparative vibration calibration.

(a3) At the same frequency point, the accelerometer is excited by the signal source, it senses the internal vibration signal and outputs the electric charge, and the output voltage of the accelerometer is collected by the same method. In order to facilitate the calculation of the transfer coefficient of the calibration coil, it is necessary to ensure that the output of the accelerometer at each frequency point is the same as the output obtained in step (a2). Measure the electrical sensitivity of accelerometer at each reference frequency point.

(a4) According to the sensitivity and electrical sensitivity measured at each frequency point, the coefficient of built-in exciting component at each frequency point can be obtained from formula (3).

Fig 5. In-situ calibration of accelerometer with vibration isolation foundation

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2. In-situ calibration of the accelerometer, using the vibration isolation foundation to simulate the on-site working environment to complete the in-situ calibration. As shown in Fig. 5, the vibration isolation foundation simulates the installation environment of the field sensor, and the sensor sensitivity is calibrated. The specific operation steps are as follows:

(b1). In the frequency range of 20~10kHz, the signal generator outputs each fixed value reference frequency of 1/3 octave, and gives an excitation signal with appropriate amplitude to excite accelerometer.

(b2). The data acquisition card collects the accelerometer output at each frequency point, and combines the input excitation signal amplitude to calculate the electrical sensitivity of the sensor at each frequency point in the simulated field environment.

(b3). According to the transfer coefficient of the calibration coil measured in the laboratory environment, combined with the electrical sensitivity of the accelerometer at each frequency point obtained in step (b2), the value of the sensitivity of the accelerometer at each frequency point in the simulated field environment can be obtained according to formula (4).

IV. EXPERIMENT RESULTS

A piezoelectric accelerometer with built-in exciting component was calibrated according to the calibration method and procedure described in section 2 and 3. Follow the operation steps (a1)~(a4), the accelerometer was calibrated in laboratory. The calibration results of the sensitivity, electric sensitivity and coefficient of built-in exciting component are shown in TABLE I and Fig.6 to 8.

TABLE I. The calibration results of the sensitivity, electric sensitivity and coefficient of built-in exciting component.

Frequency (Hz)	Sensitivity ($mV/(m/s^2)$)	Electric sensitivity (mV/V)	Coefficient ($(m/s^2)/V$)
20.0	4.987	9.904	1.986
40.0	4.956	9.896	1.997
80.0	4.927	9.888	2.007
160.0	4.898	9.882	2.018
315.0	4.865	9.878	2.030
630.0	4.844	9.877	2.039
1000.0	4.844	9.882	2.040
2000.0	4.860	9.893	2.036
3000.0	4.915	9.899	2.014
4000.0	5.027	9.903	1.970
6000.0	5.149	9.911	1.925

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8000.0	5.550	9.919	1.787
10000.0	6.216	9.929	1.597

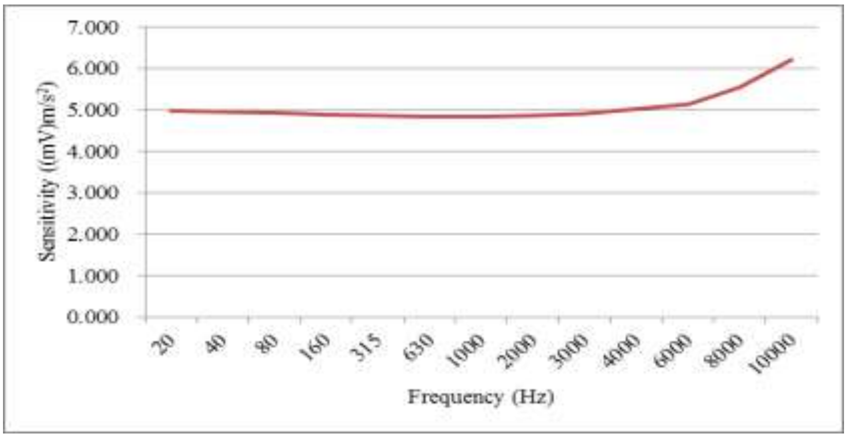

Fig 6. The sensitivity of the piezoelectric accelerometer calibrated by comparison method in the laboratory.

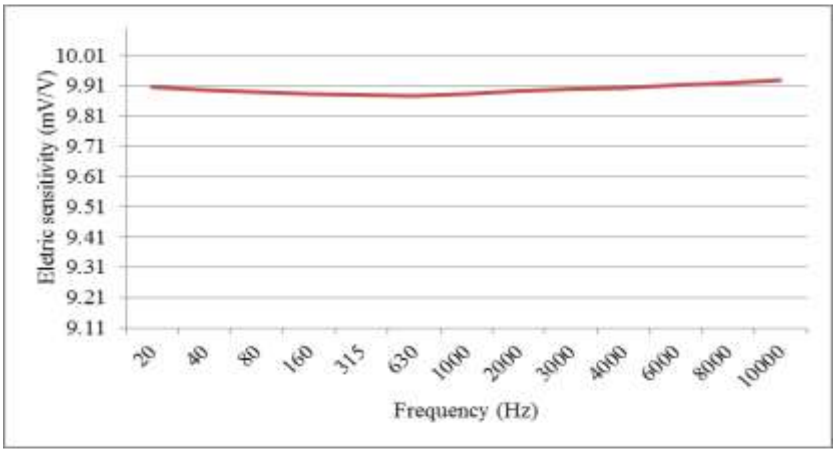

Fig 7. The electric sensitivity of the piezoelectric accelerometer calibrated by a signal generator and a voltage measuring instrumentation in the laboratory.

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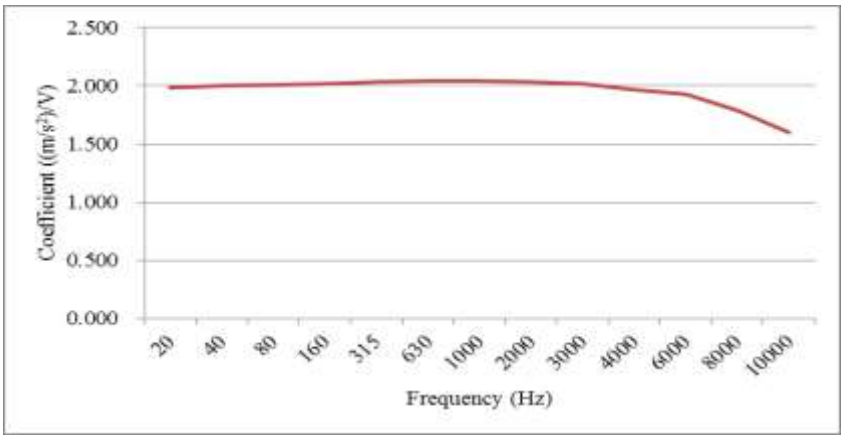

Fig 8. The coefficient of built-in exciting component calculated by the sensitivity and electric sensitivity in the laboratory.

Fig. 6 shows the frequency response characteristics of the accelerometer system. The accelerometer is a second-order motion system when the frequency is much lower than the resonance frequency, the sensitivity will increase significantly as the frequency is closer to the resonance point. Fig. 7 shows the flatness of amplitude-frequency characteristic curve of the electric sensitivity is better than one of the sensitivity especially in high frequency range. It is possibly caused by sensing modal and influence factors such as mounting resonance, and it will be required to analyze deeply. The coefficients indicate the characteristics of voltage conversion to analog acceleration. It can be seen from Fig. 8 that it is very stable in the mid-low frequency range, and decreases at high frequencies due to the presence of resonance effects.

Follow the operation steps (b1)~(b3) the accelerometer was calibrated in-situ on a structure, The calibration results of the electric sensitivity and sensitivity are shown in TABLE II. and Fig.9 and 10.

Fig.9 shows that when calibrated in situ, the electrical sensitivity trend is basically the same as that measured in the laboratory, indicating that the environment has less influence on the electrical sensitivity measurement and mainly depends on the internal structural characteristics of the accelerometer. Fig.10 illustrates the final calibration result, which is basically the same as the one calibrated in the laboratory, The experimental results show that the sensitivity parameters of the sensor obtained by in-situ calibration in the simulated field environment of the vibration isolation foundation can match the sensitivity of the sensor obtained by the laboratory calibration, and the relative error does not exceed 5%. It can be considered that the accelerometer with built-in excitation elements can realize the function of in-situ calibration. In addition, the final accuracy of sensitivity mainly depends on the external environmental influence during the in-situ calibration, whether the measurement of electrical sensitivity is standardized, etc.

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TABLE II. The calibration results of the electric sensitivity and sensitivity.

Frequency (Hz)	Coefficient ((m/s^2)/V)	Electric sensitivity (mV/V)	Sensitivity (mV/(m/s^2))
20.0	1.986	9.907	4.989
40.0	1.997	9.898	4.957
80.0	2.007	9.89	4.928
160.0	2.018	9.883	4.898
315.0	2.030	9.879	4.866
630.0	2.039	9.878	4.844
1000.0	2.040	9.882	4.844
2000.0	2.036	9.893	4.860
3000.0	2.014	9.899	4.915
4000.0	1.970	9.904	5.028
6000.0	1.925	9.912	5.150
8000.0	1.787	9.919	5.550
10000.0	1.597	9.928	6.215

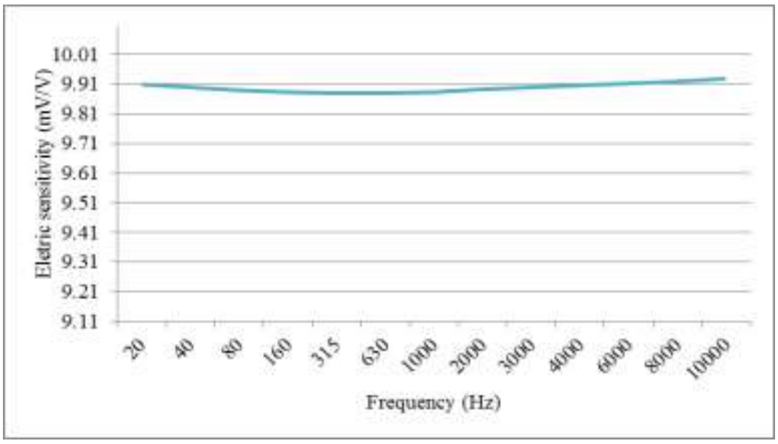

Fig 9. The electric sensitivity of the piezoelectric accelerometer calibrated by a signal generator and a voltage measuring instrumentation in-situ.

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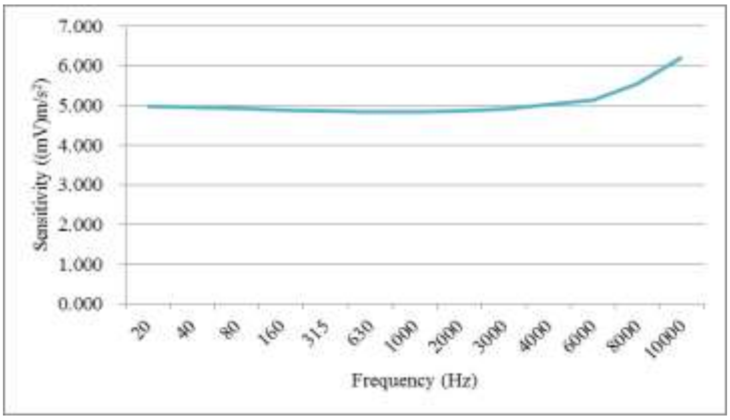

Fig 10. The sensitivity of the piezoelectric accelerometer calculated by the electric sensitivity calibrated in-situ and the coefficient of built-in exciting component gotten in the laboratory.

V.CONCLUSIONS

There are two purposes in this paper, one is to establish tractability chain for the in-situ calibration of the piezoelectric accelerometer with built-in exciting component; the other is to verify the feasibility of the in-situ calibration method. Modal analysis and experiments reveal that the electric sensitivity can possibly be used for the in-situ calibration of this kind of accelerometer, and traceable to primary or secondary vibration calibration standard. The realization of in-situ calibration method helps to improve the correctness and reliability of the measurement results, and provides convenience for the calibration of the accelerometer's amplitude-frequency characteristics, sensitivity and linearity. For long-term seismic observation instruments and engineering vibration measurement instruments, the accelerometer with built-in exciting exciting component can be used to complete its self-calibration, which has very important practical value.

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