Development of Piezoelectric Actuator Calibration System

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Abstract. Piezoelectric actuator is used for the period of time will cause the fading of efficacy. Hence, it is an important issue about providing convenient, fast and accurate calibration mode. In the past, the values of calibration parameters are record by manual. Therefore, this method will cause the risk of personal errors. In this investigation, a self-developed automatic calibration system for piezoelectric actuator is proposed. The automatic calibration system integrated with the measurement software processing module, scheme of interferometer system, piezoelectric actuator and the voltage amplifier has been employed for the calibrating of piezoelectric actuator parameters, e.g. hysteresis and maximum stroke. Comparison experiments between the calibration parameters results of self-developed interferometer system and Renishaw RLE-10 system reveal that the maximum stroke error is 13.3% and the maximum hysteresis error is 14.6%. These results are all in the error range which is provided by the firm.

Introduction

Piezoelectric actuator is the actuating element of conversion electrical energy into mechanical energy. Due to high displacement resolution, non-electromagnetic interference, rapid response and small volume, the piezoelectric actuators are widely applied to the engineering of micro-vibration and micro-displacement, e.g. semiconductor engineering, ink jet printers, scanning probe microscopes and atomic force microscopes etc. Due to the piezoelectric actuator is used for the period of time, the performance may occur deviations. Therefore, the parameters of piezoelectric actuator must be measured by self-developed interferometer system and Renishaw RLE-10 system. And then compare the measurement data with inspection data which is provided by the firm in order to calibrate the present characteristics and status.

The method of calibrating the piezoelectric actuator is based on the displacement sensor and uses the voltage driving the piezoelectric actuator to measure and calibrate. If from controlling the output of voltage to record of data are all by manual operation, it is time-consuming and may cause the risk of personal errors. In this paper, the calibration system which is constructed by the self-developed software programs and hardware equipment has the functions of saving time and without manual measurement. This system is to achieve the purpose of calibrating piezoelectric actuator.

Parameters and Methods of Calibration

Laser interferometer is a non-contact measurement tool. It has the advantages of high resolution, high measurement range and less limitations, so laser interferometer is used as the calibration tool in this paper.

Parameters of Calibration

These two parameters, hysteresis and maximum stroke, are used as the calibration parameters of piezoelectric actuator. And then compare the measurement results of self-developed interferometer with the measurement results of Renishaw RLE-10 interferometer and verify with the inspection standards of the firm as shown in Table 1.
Table 1. Inspection standards.

| Errors            | Inspection standards of the firm |
|-------------------|----------------------------------|
| Hysteresis error  | <15%                              |
| maximum stroke error | ±15%                            |

Methods of Calibration

The Voltage-displacement characteristics curve of piezoelectric actuator as shown in Figure 1. From minimum output voltage to maximum output voltage is divided to appropriate measurement points to measure. According to the reference information, while measuring the parameters of piezoelectric actuator from minimum output voltage to maximum output voltage is divided to ten measurement points and nine frequencies of repeated measurement.

![Voltage-displacement characteristics curve](image)

Figure 1. Voltage-displacement characteristics curve.

The Design of Calibration System

There would be three parts developed in this project as shown in Figure 2, including 1. measurement software processing module, 2. scheme of interferometer system and 3. piezoelectric actuator and the voltage amplifier.

![Calibration system](image)

Figure 2. Calibration system.

Measurement Software Processing Module

Measurement software processing module is contained the capture card and the analog to digital conversion card. The capture card can input two signals, and then the signals are divided into one-quarter cycle in order to count. Analog to digital conversion card is used to convert the continuous analog signals to the form of discrete digital signals. With the judgment of computer programmable logic, this module is a part of signal processing module.
Scheme of Interferometer System

These interferometer system contains three parts, including laser light source, interferometer probe and signal processing circuits. Laser light source passes through a special optical arrangement and generates the interference signals in the Fabry-Perot resonant cavity. And then, by using the signal processing circuits to amplify the signals and adjust the DC offset.

Theoretical Equations of Intensity Distribution

The structure of Fabry-Perot interferometer as shown in Figure 3, Laser light source passes through the BS into the optical cavity. The one eighth wave plate in the cavity is employed to form interference signals with the orthogonal phase shift. And the polarization axis of the wave plate must be the same as that of PBS. By this arrangement, the orthogonal signal can be acquired by two photodiodes (PDs) and then transmitted to the signal processing module.

![Figure 3. Structure of Fabry-Perot interferometer.](image)

The corresponding equation of intensity distribution can be derived from equation (1) to (8). The amplitude of the firstly reflected beam is expressed as $A_{s1}$ (Eq. 1) and that of the whole interference beam is denoted with $A_{sN}$ (Eq. 2), where $A_0$ is the amplitude of Laser source, $R_1, R_2$ and $T_1$ are the reflectance and transmittance of the coated mirror, $T$ is the resultant transmittance of the optical cavity, and $N$ is the order number of the backward reflected light beam.

\[
A_{s1} = \frac{1}{2\sqrt{2}} A_0 R_1
\]  
(1)

\[
A_{sN} = \frac{1}{2\sqrt{2}} A_0 \sqrt{R_1^{N-2} T_1 T^{N-1} R_2^{N-1}} \quad (N \neq 1)
\]  
(2)

The corresponding electric field function of the interference beam can be described as Eq. 3 and 4, where phase difference $\delta$ is equal to $\frac{\lambda d}{8\pi}$ and $d$ and $\lambda$ imply cavity length and wavelength.

\[
E_{sN} = A_{sN} \cos[\alpha t + kx + (N-1)\delta]
\]  
(3)

\[
E_{pN} = A_{pN} \cos[\alpha t + kx + (N-1)\delta - \frac{\pi}{2}]
\]  
(4)

By Eq. 5 and 6 the intensity distribution of s-type and p-type can be denoted with following equations (Eq. 7 and Eq.8)

\[
I_s = E_s \times E_s^*
\]  
(5)
\[ I_p = E_s \times E_s^* \]  
(6)

For s-type (PD1) intensity:

\[ I_s = \frac{1}{8} A_0^2 \times \left[ \frac{R_1 + (R_2 (T_1 - R_1) T)^2 + 2 \sqrt{R_1} \sqrt{R_2} (T_1 - R_1) T \cos(\delta)}{1 + (\sqrt{R_1} \sqrt{R_2} T)^2 - 2 (\sqrt{R_1} \sqrt{R_2} T) \cos(\frac{\delta - \frac{\pi}{2}}{2})} \right] \]  
(7)

For p-type (PD2) intensity:

\[ I_s = \frac{1}{8} A_0^2 \times \left[ \frac{R_1 + (R_2 (T_1 - R_1) T)^2 + 2 \sqrt{R_1} \sqrt{R_2} (T_1 - R_1) T \cos(\delta - \frac{\pi}{2})}{1 + (\sqrt{R_1} \sqrt{R_2} T)^2 - 2 (\sqrt{R_1} \sqrt{R_2} T) \cos(\frac{\delta - \frac{\pi}{2}}{2})} \right] \]  
(8)

The interferometric intensity simulations with the normalization processing as shown in Figure 4.

**Signal Processing Module**

The employed Laser is an unstable He-Ne Laser with the wavelength of about 632.8 nm. After the interference processing and light division by PBS, the analog signals from the PDs are transmitted into the amplifier. The circuits of differential and non-inverting amplifier are merged in the controlled by another part of signal processing module. Finally, the measurement results will be transferred to PC for displaying.

Figure 5 demonstrates the procedure of the interference signal processing. The orthogonal signals are magnified and adjusted through the non-inverting and differential amplifier. The parameters errors are calculated by measurement program.

After through the amplifier, the signal of AC term and DC term will simultaneously amplify as shown in Figure 6 (a). In order to avoid that status of the signal leaving out caused by the DC term, we let the signal through the differential amplifier to eliminate the DC term. Finally, the signal can pass the logic gate of calculating by capture card as shown in Figure 6 (b).
Piezoelectric Actuator and the Voltage Amplifier
The piezoelectric actuator belongs to the inverse piezoelectric effect. By giving the external voltage to the piezoelectric actuator, the piezoelectric materials will cause the change of length. The change of length is proportional to the electric field. Voltage source is connected to the input terminal of the voltage amplifier and adjusts the appropriate amplifying magnification. Then output the voltage to the piezoelectric actuator.

Conclusions
This The Fabry-Perot interferometer serves as reference standard for the calibration of piezoelectric actuator. The whole measuring range is 20 µm with ten measuring points. Due to the reference information, each cycle must be repeated nine times. The measurement results have been illustrated in Figure7 (a) and Figure7 (b).

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