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Research on Dynamic Calibration of Piezo-two-dimensional Force Sensor

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Abstract: Based on the piezoelectric effect of piezoelectric quartz crystal, a two-dimensional force sensor with good dynamic characteristics is designed, whose sensitive component is single-cut piezoelectric quartz wafers, and it realizes the measurement of force by measuring the charge which is generated by piezoelectric quartz crystal. This paper analyzes measurement principle of the sensor based on the mechanics of materials and gives structure of the sensor. Dynamic calibration system of the sensor is designed, and the curves between sensor output and input are obtained by dynamic calibration experiment and data analysis. This article provides a new way of thinking for in-depth study in dynamic calibration of the sensor and accurate measurement.

Keywords: Sensor, Dynamic Calibration, Dynamic force, Dynamic torque.

1. Introduction

With the development of modern high-precision test equipment, the means and methods of static measurements of force are more and more matured, and the measurement accuracy is also rising. With the development of science and technology, people are setting foot in more fields, and new demands on the measurement technique have also been put forward. Dynamic force measurement has increasingly attracted attention [1].

Gu Baodong et. al. [2] analyzed precision of calibration system using interval arithmetic, and deduced specific expression of calibration accuracy, and studied Frequency-change characteristics of the system with additional mass. Austrian Qi [1] presented dynamic calibration device for force sensor, and it could realize dynamic calibration with dynamic loading. Yusaku Fujii [3] discussed the way of establishing dynamic calibration systems, and described three methods of measuring dynamic response of the sensor with different forces. Rolf Kumme [4] calibrated force sensor by using comparative law, that is to say, using the standard sensor to conduct dynamic calibration. D. J. Mee [5] analyzed different technologies of calibrating force balance, and supersonic instrument with short duration was used. J. P. Damion [6] described different methods of determining transfer function of sensors, and introduced the equipment which was used in dynamic calibration of sensor. A. Fisher, S. Watkins and J. Watmuff [7] introduced a portable calibration system that can quickly and accurately calibrate pressure measurement system. David J. Mee

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[8] described different techniques of calibrating stress wave force balance.

With the rapid development of testing technology, it has been sufficiently attracted attention. The dynamic characteristic is a key parameter of the force sensor, and dynamic calibration is essential for sensor to measure dynamic force accurately and reliably. The requirements of measurement system measuring dynamic signal are that it could measure the signal quickly and accurately and reproduce changed signal waveform truly [9]. This paper proposes a two-dimensional force sensor based on single-cut piezoelectric quartz, and analyzes its measuring principle. The dynamic calibration of the sensor is also conducted, and the dynamic follow-up characteristic of the sensor is studied.

2. Measuring Principle

The measuring principle of measuring moment is analyzed based on Mechanics of Materials. Fig. 1 shows longitudinal section moment diagram of quartz group. According to relation between moment and distributed load in Mechanics of Materials, distributed force of piezoelectric quartz group which is caused by the effect of torque is linear distribution. Wherein, M is the torque acted on the piezoelectric quartz group ,while R and r are the radius of outer and inner circles of piezoelectric quartz group, respectively, and q represents the uniform load. F1 and F2 mean left integrated force and right integrated force, respectively, and l1 and l2 indicate distance from integrated forces to center of crystal group.

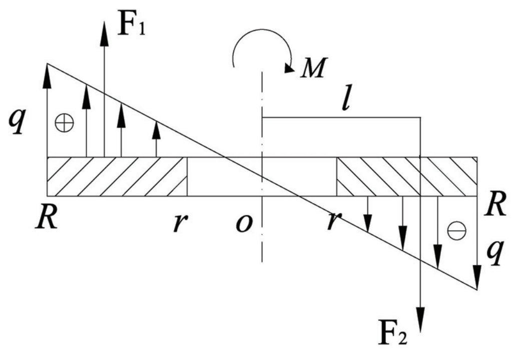


Fig. 1. Torque measurement schematic.

According to stress analysis，moment equation can be listed as formula (1):

$$\frac{1}{2}q\cdot R\cdot\frac{2}{3}\cdot R-\frac{1}{2}\left(\frac{r}{R}q\right)r\cdot\frac{2}{3}r=\frac{M}{2}, \quad (1)$$

q could be obtained by calculating formula (1).

$$q=\frac{3RM}{2\left(R^{3}-\mathrm{r}^{3}\right)}$$

Therefore, the left integrated force F_1 of piezoelectric quartz group can be calculated.

$$F_1=\frac{3M}{4}\left(\frac{R+\mathrm{r}}{R^2+Rr+r^2}\right)$$

Similarly, the right integrated force F_2 of piezoelectric quartz group can also be obtained. Therefore, according to the formula (2), moment M applied to the piezoelectric crystal can be obtained.

$$F_1l_1+F_2l_2=M\ , \quad (2)$$

where l_1 and l_2 are determined by calibration experiments. The equation (2) shows that it is linear relationship between the input torque and output voltage of sensor.

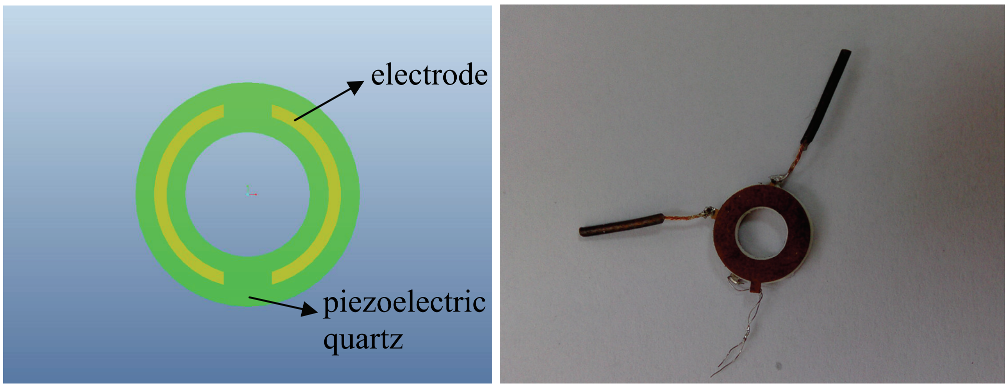
3. Sensor Structure

On the basis of measuring principle, this paper uses the single-cut piezoelectric quartz crystal, namely, piezoelectric quartz group is made of x0 cut piezoelectric quartz crystal. When the force combined with moment are applied to piezoelectric quartz crystal, the potential distribution of left and right parts of the crystal is asymmetric, so this article proposes piezoelectric quartz group with dual-electrode structure that could measure two-dimensional force.

Compared with single-electrode structure, dual-electrode structure could reduce the mutual interference between two parts of single-electrode and ensure minimal loss of the charge generated by piezoelectric quartz crystal. In this paper, the sensor uses the piezoelectric quartz crystal whose thickness is 1mm and outer diameter is 9 mm. The structure and in-kind of crystal group are shown as Fig. 2 (a) and (b), respectively.

4. Dynamic Calibration of the Sensor

According to calibration principle and method of the sensor, dynamic calibration system is designed as shown in Fig. 3, and the block diagram of the calibration system is showed as Fig. 4. The experiment is designed to calibrate sensor when the dynamic loading is applied to the force sensor. Output section of dynamic load and data collection section compose calibration system. The dynamic load is outputted by exciter in the calibration process, and the input signal of the exciter is outputted by real-time controller that is controlled by program of software controldesk, and program is compiled from the algorithm that is edited in the Simulink module of software Matlab. Dynamic force could be loaded continuously to the sensor by editing different algorithms, and the value and frequency of force could also be changed. The experiment is done by increasing the frequency of the input signal of exciter to adjust the output amplitude of the exciter. Real-time control system could output the real-time signal and collect real-time data, and display graphics of real-time signal simultaneously. In the role of dynamic loading, the output end of the sensor is connected to the charge amplifier firstly, and the signal is amplified, and then the charge amplifier is connected to the data collection port of real-time controller. The purpose of this experiment is to study the output change of sensor with the change of dynamic load, and the change of dynamic load that is applied to the sensor is obtained by using laser displacement sensor to measure the change of vibration displacement of mass block, which is connected to the sensor.



(a) (b)

Fig. 2. The structure (a), and in-kind (b) of piezoelectric quartz crystal group

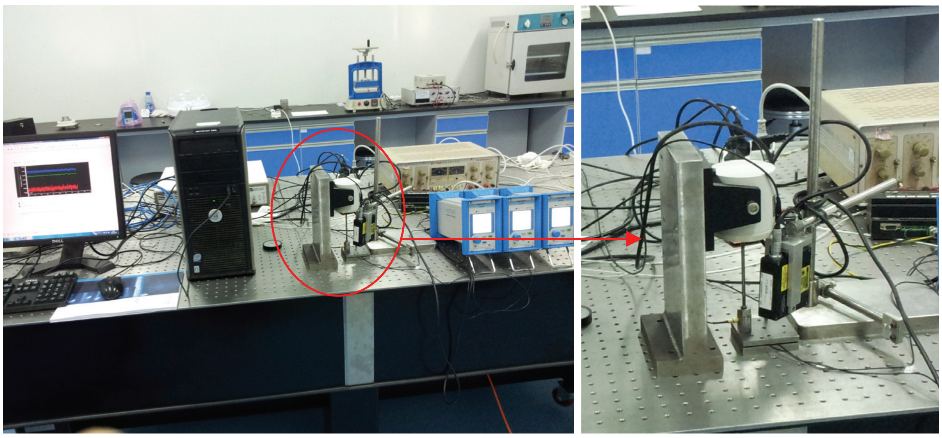


Fig. 3. Dynamic calibration system of the sensor.

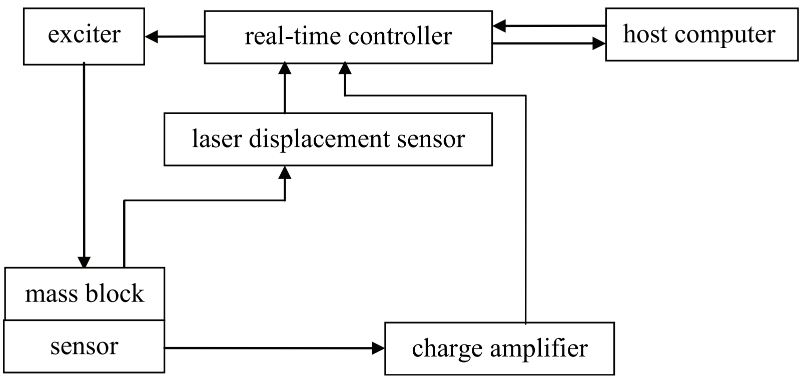


Fig. 4. Block diagram of the calibration system.

4.1. Dynamic Force Calibration Experiment

In the static calibration experiment of the sensor, usually, the calibration curve is obtained by the method of applying normal load to the sensor. The linearity of this piezoelectric sensor is excellent in the static calibration. In the dynamic calibration experiment, the output signal of the sensor could be monitored in real time when the dynamic force is applied to the sensor. The relationship between output signal and the input signal of the sensor is expressed by the relationship between output voltage and the vibration displacement of mass block that is connected to the sensor, and the curve is shown as Fig. 5.Wherein, the solid line with the node is practical Curve, and another curve is fitting curve with the method of square law. It can be seen from the Fig. 5, output voltage signal of the sensor increases linearly with the increase of the vibration displacement of the mass block, namely, the linearity of the sensor under the effect of dynamic force is good.

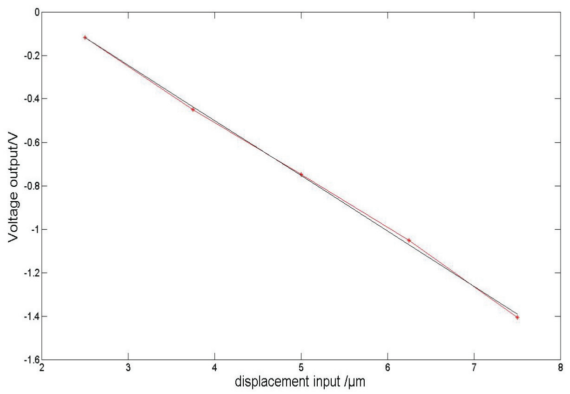


Fig. 5. The curve of dynamic force calibration.

4.2. Dynamic Torque Calibration Experiment

Static moment calibration of the sensor was conducted in the static calibration experiment of the sensor, and the linearity of calibration curve is excellent. Dynamic torque calibration experiment is designed to study the linearity between output voltage of the sensor and the input torque that is continuously changed over time. Fig. 5 shows that the curve between the output voltage of the sensor and the vibration displacement of mass block, namely, it is equivalent to the curve between output voltage of the sensor and input torque that is applied to the sensor. Wherein, the solid line with the node is practical curve, and another curve is fitting curve with the method of square law. It can be seen from the Fig. 6, the linear relation between output voltage and input torque is perfect.

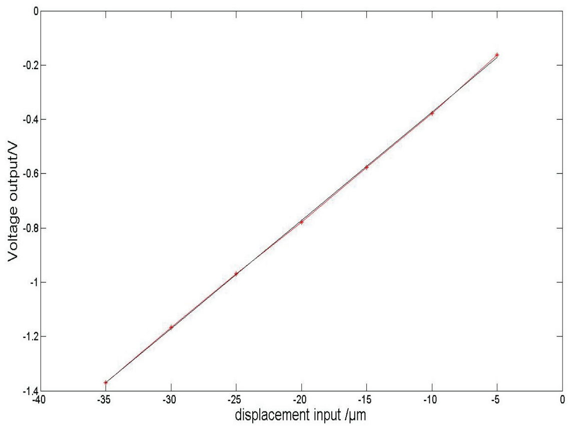


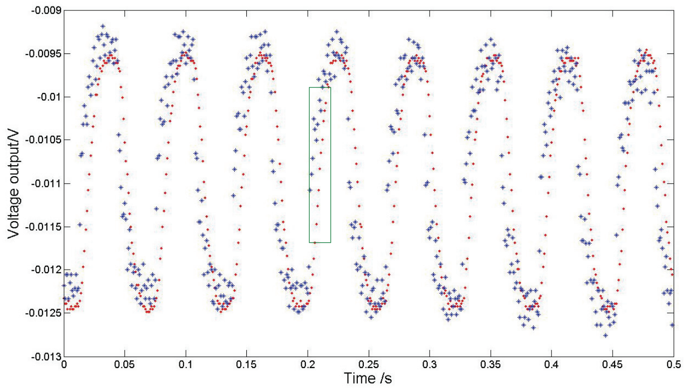
Fig. 6. The curve of dynamic torque calibration.

4.3. Dynamic Following Feature Experiment

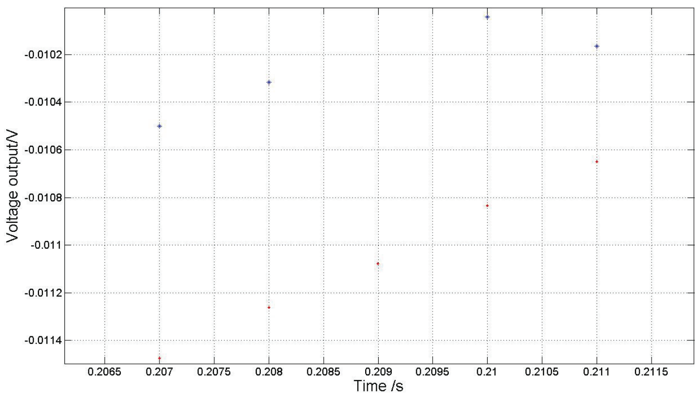
In order to test the dynamic performance of the sensor, dynamic following feature experiment is designed. Output voltage signal of the sensor is measured When the angular velocity of input dynamic force is100rad/s. Fig. 7 (a) shows comparison between output voltage and the input force of the sensor, and the smaller scatter indicates the force signal while the larger represents voltage signal of the sensor. Fig. 7 (b) is the partially enlarged view of the box area from Fig. 7 (a), and what can be seen from Fig. 7 (b) is that there is no time difference between voltage signal and the corresponding force signal, therefore, the dynamic following feature of this sensor is good.

5. Conclusion

In this paper, measurement principle based on Mechanics of Materials of two-dimensional piezoelectric force sensor is analyzed, and the sensitive element with special Dual-electrode structure made of single-cut piezoelectric quartz crystal is proposed. The dynamic calibration system including the real-time control system, the charge amplifier, and the host computer etc. is designed. Calibration experiments of dynamic force and dynamic torque and dynamic following feature experiment are designed and completed. According to data achieved from the dynamic calibration experiments, the curves between output of the sensor and dynamic force and dynamic torque are obtained, and the dynamic following characteristic curve of the sensor is also plotted. This sensor that is loaded with the dynamic loads, not only has good linearity, but also has excellent dynamic follow feature. The research results lay a new foundation for the dynamic calibration technology of the force sensor.



(a)



(b)

Fig. 7. The comparison between output and input of sensor (a), and Partial enlarged view (b).

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