Automatic Deformation Measurement Equipment for PZT Wafer

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Abstract. PZT wafers are the core driving parts to adjust the laser resonant cavity length of laser gyro. Usually, the PZT wafers are used in pairs, and the paired PZT wafers need to have close piezoelectric coefficients. To handle the pairing and screening of PZT wafers, an automatic deformation measuring equipment is developed by using a cartesian-coordinate robot frame, in which multiple photoelectric sensors are used to detect the key motion position automatically. Besides, vacuum absorption technology is also used in picking, carrying and placing PZT wafers to protect them from accidental injury. When driving voltage is applied to PZT wafer, the resulting micro displacement is measured by dual opposite inductive probes with relative measurement principle. This measuring strategy eliminates the influence of placement error of PZT wafers on the final measuring result. Compared with the existing manual measurement, the efficiency can be improved by 60%. The experimental results show that the equipment has high reliability and consistency. The measurement accuracy in full scale is no more than 0.5 \( \mu m \) and the repeat accuracy is superior to 0.1 \( \mu m \).

1. Introduction

Laser gyro is an optical inertial device that measures the rotation velocity of object. It is widely used in aerospace field [1-2]. The working principle of laser gyro is to detect the optical path difference of two reverse laser beams in closed annular optical path, thereby to calculate the angular velocity of rotation[3]. Laser gyro needs to work at stable frequency. But its laser resonant cavity length usually varies in micron scale due to the influence of environmental factor, such as temperature and mechanical vibration. This leads to frequency variations which has fatal impact on working stability of laser gyro[4-5]. Therefore, laser gyro contains a displacement compensator to adjust the laser resonant cavity length so as to stabilize the working frequency [6]. Usually, the displacement compensator works based on principle of inverse piezoelectric effect, at this point, the PZT wafer acts as the core driving part [7-8]. The PZT wafer needs to be used in pairs, and the paired PZT wafers need to have close deformations at the same driving voltage. Therefore, the piezoelectric property, referring in particular to the deformation of PZT wafer, should be measured and matched before using.

Currently, manual measurement method is usually employed in production field. The manual measurement is inefficient and hard to guarantee the testing quality due to different workers' operation. This seriously affects the follow-up assembly work of laser gyro. Therefore, it is necessary to develop an automatic measuring equipment to deal with in-site batch measurement of PZT wafers with high efficiency and accuracy. For micron-sized deformation measurement of PZT wafer, optical and
electrical methods are usually used. Optical method mainly refers to laser interferometry measurement, employing single-beam or double-beam laser interferometer [9-10]. The laser interferometry measurement can reach resolution of $10^{-14}$ m. However, optical measuring system is generally sensitive to the working condition [11]. And complex optical components for interferometry make the system ponderous and expensive. Moreover, it requires high technical skills for operators. Therefore, the laser interferometry measurement system is mainly used in laboratory for small batch and high precision measurement tasks. The electrical methods mainly include capacitor method [12] and inductance method [13]. For annular PZT wafer, the testing surface is narrow arc surface. In this case, it is easy to produce edge effect by using capacitance sensor. Comparatively speaking, the inductance method has low requirement on the testing surface and moderate precision. Moreover, it is easy for implementation and system integration to cooperate with automated production and detection. Therefore, inductance method has a much wider applicability for the advantages of simple operation, stable performance and high reliability.

To sum up, in order to deal with in-site batch measurement of PZT wafers with high efficiency, an automatic measuring equipment for PZT wafer of laser gyro is developed by using a cartesian-coordinate robot frame and dual opposite inductive probes with relative measurement principle. It is designed to meet PZT wafer with annular/rectangular shapes and multiple sizes. What's more, it has high reliability, consistency, and measurement efficiency.

2. Overall design of the equipment

As shown in figure 1, the PZT wafers are annular or rectangular with thickness of 0.4mm. According to the user requirement, the design objectives of the equipment are as follows: The measurement accuracy in full scale is no more than 0.5 µm and the repeat accuracy is superior to 0.1 µm. The measuring force is less than 0.2 N and the driving voltage range is DC 0~300 V. It can complete the task of automatic loading, measuring and sorting operations of 50 PZT wafers in a single batch.

![Figure 1. The PZT wafers to be test](image1)

![Figure 2. Overall design scheme of this equipment](image2)

The working process can be divided into three steps: loading/blanking, measuring, and sorting. Concretely, the loading process includes picking, carrying and placing PZT wafers. In order to avoid damage on PZT wafers during loading process, the vacuum adsorption picking mode is adopted. The cartesian-coordinate robot frame is used to locate the PZT wafer accurately. The measuring process includes accurate voltage loading and micron-sized deformation measurement. This equipment is used for in-site batch measurement of PZT wafers, which requires high reliability, operability and appropriate accuracy simultaneously. Therefore, inductance method is preferred, and dual opposite inductive probes with relative measurement principle is employed to reduce the requirements for the positioning accuracy. The accuracy of the driving power supply directly affects the measurement accuracy. So dedicated power supply for PZT with high control accuracy and stability is used. The sorting process is to match PZT wafers with similar piezoelectric property based on measuring results. This can be achieved through carrying PZT wafer to different recovery bins after measurement. Based on the above analysis, three main functional modules are designed, i.e., loading/blanking module, carrying module and measuring module. The overall design scheme is shown in figure 2.
3. Equipment construction and working principle

The equipment is installed on an optical platform and multiple rubber vibration isolation cushions are set up under the platform to achieve good stability.

3.1. The loading/blanking module

The loading/blanking module consists of a feeding table and multiple recovery bins, as shown in figure 3. The feeding table mainly consists of an air cylinder and centring clamping jaw. Before measurement, the PZT wafers are stacked on the feeding table with relative freedom. Then the cylinder acts to drive the clamping jaw to tighten inward. Thus central alignment of the PZT wafers are completed.

After measurement, the PZT wafers are sorted based on measuring results. To avoid the stack of congeneric PZT wafers losing balance and toppling over, different type baffles are mounted on a special mounting plate to construct recovery bins. The mounting plate is designed as an independent part to facilitate disassembly for PZT wafers recycling. There are total six recovery bins, and one of them is for unqualified PZT wafer.

3.2. The carrying module

The carrying module completes the picking, carrying and placing operation of PZT wafers. It adopts planer type structure that consists of x-axis and z-axis, as show in figure 4. The x-axis and z-axis are used for horizontal and vertical motion to pick/place the PZT wafer. The picking arm and the upper electrode are parallely fixed on z-axis by connection blocks, and they are also fixed together via a common mounting beam. The mounting beam is separate from z-axis. The z-axis is equipped with photoelectric sensors, and the upper electrode and mounting beam are equipped with respective light barriers. During picking operation, when the picking arm is in contact with the PZT wafer, there will be relative motion between the mounting beam and z-axis due to the linear bearing embedded in right connection block. When the theoretical position is achieved, the light barrier triggers the corresponding photoelectric sensor to generate stop signal for z-axis. If this stop signal is responded incorrectly by accidents, z-axis will move on and the light barrier mounted on mounting beam triggers the top photoelectric sensor. By this time, an emergency stop signal is generated, which stop x-axis and z-axis simultaneously through interruption control. This protection strategy avoids damage on equipment and PZT wafer due to excessive motion of z-axis. The picking arm adopts double vacuum chucks to ensure stable picking operation. The vacuum chucks are mounted at the bottom end of the hollow connecting rod. There is a fixing ring at the upper part of the connecting rod to prevent it from falling off due to gravity.

The relative measurement using dual opposite inductive probes eliminates the influence of placement error of PZT wafers on the final measuring result. Therefore, the motion accuracy of the picking module is not required to be very high, but the travel range should be considered carefully.

3.3. The measuring module

The measuring module completes the voltage loading and micro-deformation measurement of PZT wafer. It mainly consists of measuring platform, inductive probes, and the upper and lower electrodes, as shown in figure 5 and figure 6.
An electric rotating platform is used as the main part of measuring platform, so as to measure the displacement of PZT wafer in different directions. Two inductive probes are mounted on two y-axes locating on opposite sides of the measuring platform. The lower electrode is integrated to the measuring platform, while the upper electrode is integrated to z-axis as shown in figure 4. During measurement operation, the PZT wafer is placed on the lower electrode by carrying module. Then the picking arm moves away and the upper electrode moves down to impact the PZT wafer. The two y-axes drive inductive probes moving towards to get in touch with PZT wafer. The y-axes stop until both two inductive probes have a certain amount of compression. Finally, the driving voltage is loaded through the upper and lower electrodes. PZT wafer is adsorbed on the lower electrode through two adsorption holes after placement. This vacuum adsorption works until the upper electrode completes the impaction operation. The upper electrode is designed as the combination of an elastic probe and a spherical bearing, as shown in figure 6. This structure makes the upper electrode has automatic attitude adjustment function, so as to overcome the problem of local force and incomplete contact. The upper electrode is equipped with a light barrier on its sleeve. Thus the principle of position control and hardware protection are similar to that of picking arm.

Likewise, the relative measurement principle reduces the requirements for accuracy of the moving platform in measuring module. The key parts are the inductive probes which requires low measuring force and high accuracy. In practice, inductive probes of GTL222-A from TESA SA is employed. The stability of the driving voltage directly affects the final measuring results. It is necessary to select a driving power supply with high control precision. In addition, it must be programmable to achieve automatic operation. Finally, dedicated power supply for PZT, XE501-C from Harbin Core Tomorrow Science & Technology Co., Ltd., is selected. The most important parameters are Output voltage range, voltage stability and output ripple. They are 0~300 V, < 0.1%F.S. /8hours and 5±20% mV, respectively. Usually, the piezoelectric property of PZT wafer characterized by deformation-voltage characteristic curve can be considered as linear. The user provides that the deformation of PZT wafer to be test is less than 0.02 µm with each voltage change of 1 V. Based on table 3, the maximum deformation of PZT wafer is about 0.02 µm/V×300 V=6 µm, and the voltage fluctuation at full-scale output is about 0.3 V, which will cause measuring error of 0.006 µm << 0.5 µm.

4. Measurement experiment and data analysis
The physical equipment is shown in figure 7. In order to check the performances of this equipment, an experiment using real annular PZT wafers was carried out.
Firstly, three arbitrary PZT wafer was selected and measured for 10 times at the same voltage of 100 V. The measuring results are summarized in Table 1. It can be seen that the extreme deviation of measuring result for the same PZT wafer is 0.07 μm < 0.1 μm. This demonstrates that the repeat accuracy of the equipment meets the design objective.

| Test serial number | PZT wafer1 (μm) | PZT wafer2 (μm) | PZT wafer3 (μm) |
|--------------------|-----------------|-----------------|-----------------|
| 1                  | 1.61            | 1.56            | 1.48            |
| 2                  | 1.63            | 1.50            | 1.47            |
| 3                  | 1.63            | 1.52            | 1.49            |
| 4                  | 1.63            | 1.57            | 1.47            |
| 5                  | 1.63            | 1.55            | 1.47            |
| 6                  | 1.64            | 1.51            | 1.46            |
| 7                  | 1.65            | 1.55            | 1.43            |
| 8                  | 1.65            | 1.50            | 1.50            |
| 9                  | 1.66            | 1.53            | 1.47            |
| 10                 | 1.67            | 1.55            | 1.47            |

Subsequently, the same batch of 50 PZT wafers were measured by this equipment and existing manual measurement method at 100 V, respectively. The measurement processes cost 2 min and 5 min, respectively, which means the work efficiency increases by 60%. Table 2 shows part of measuring results. After data processing, the average value of this equipment is 1.454 μm with standard deviation of 0.032 μm, and the average value of manual measurement is 1.451 μm with standard deviation of 0.084 μm, respectively. The dispersion degree of measuring result of this equipment is smaller, which indicates better reliability and consistency.

| Test serial number | Equipment measurement data (μm) | Manual measurement data (μm) |
|--------------------|---------------------------------|-----------------------------|
| 1                  | 1.45                            | 1.48                        |
| 2                  | 1.47                            | 1.47                        |
| 3                  | 1.46                            | 1.52                        |
| 4                  | 1.49                            | 1.38                        |
| 5                  | 1.49                            | 1.47                        |
| 6                  | 1.46                            | 1.44                        |
| 7                  | 1.46                            | 1.52                        |
| 8                  | 1.45                            | 1.48                        |
| 9                  | 1.50                            | 1.36                        |
| 10                 | 1.41                            | 1.43                        |
| ...                | ...                             | ...                         |

In this work, the maximum deformation of PZT wafer is about 6 μm as mentioned in the last paragraph of section 3.3. Thus the maximum permissible error of the inductive probe is $0.2 + 2.4 \times 6 = 0.2 + 14.4 = 14.6$ μm.
0.2 µm. The measurement accuracy can be approximated as 2 times of the resolution of the inductive probe due to relative measurement principle. Therefore, the final measurement accuracy is much better than the design objective.

5. Conclusion
Based on comparative analysis of the existing techniques of deformation measurement for PZT wafer, a dedicated deformation measurement equipment is developed in this work. This equipment adopts cartesian-coordinate robot frame and two inductive probes with relative measurement principle. It realizes automatic operation of loading/blanking, measuring and sorting for PZT wafer, at the same time, it has self-protection function. Compared with the existing manual measurement in production field, the measurement efficiency can be improved by 60%, and the repeat accuracy is less than 0.1 µm. Obviously, it has higher reliability and consistency, which provides an efficient method for massive pairing application for PZT wafers. At present, the equipment is designed to meet only annular and rectangular wafer. The application scope of the equipment can be further expanded by modifying the measuring module and loading/blanking module.

6. References
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Acknowledgments
This research work was supported by Major Project of Basic Scientific Research of Chinese Ministry (Grant No. JCYK 2016 205 A003), National Science and Technology Major Project of China (Grant No. 2013ZX04001091), and the National Natural Science Foundation of China (No. 51621064).