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Multi-sensor control for precise assembly of optical components

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Abstract In order to perform an optical assembly accurately, a multi-sensor control strategy is developed which includes an attitude measurement system, a vision system, a loss measurement system and a force sensor. A 3-DOF attitude measuring method using linear variable differential transformers (LVDT) is designed to adjust the relation of position and attitude between the spherical mirror and the resonator. A micro vision feedback system is set up to extract the light beam and the diaphragm, which can achieve the coarse positioning of the spherical mirror in the optical assembly process. A rapid self-correlation method is presented to analyze the spectrum signal for the fine positioning. In order to prevent the damage of the optical components and realize sealing of the resonator, a hybrid force-position control is constructed to control the contact force of the optical components. The experimental results show that the proposed multi-sensor control strategy succeeds in accomplishing the precise assembly of the optical components, which consists of parallel adjustment, macro coarse adjustment, macro approach, micro fine adjustment, micro approach and optical contact. Therefore, the results validate the multi-sensor control strategy.

1. Introduction

The ring laser gyroscope is a main component in the strapdown inertial navigation system. It is widely used in many fields, such as aircraft, rockets, missiles, naval vessels, ships, vehicles, etc.[1] Especially in the military field, ring laser gyroscopes occupy an important position.[2] The ring laser is a basic component of the ring laser gyroscope. However, in the production process of ring laser gyroscopes, each laser's resonator, light path and reflecting mirrors will have some errors, due to factors such as materials and machining.[3] Therefore, in order to compensate for the errors to satisfy the operating requirements of the ring laser gyroscope, the positions of the reflecting mirrors must be adjusted on the laser accurately.

In the ring laser, the process of adjusting and assembling the spherical mirrors is called resonator adjustment. Resonator adjustment is a key step in the process of manufacturing ring laser gyroscopes. It is not only directly related to producing laser light in the resonator, but also influences the performance of the ring laser gyroscope. At home and abroad, the research of ring laser gyroscope technology focus on such problems as lock size, threshold current, noise, zero-drift, and so on.[4–8]

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However, the research on resonator adjustment is seldom involved.

Resonator adjustment is a complex process. In order to fulfill the optical assembly, some sensors must be applied to adjust and assemble the spherical mirrors accurately. A multi-sensor control system is presented to monitor the optical assembly, which consists of a vision sensor, an attitude sensor, a photoelectric sensor and a force sensor. Moreover, a control strategy is developed to accomplish the optical assembly. Finally, a set of precise optical assemblies are accomplished by the control strategy.

2. Precise assembly principle of optical components

As Fig. 1 shows, there are four reflecting mirrors in the ring laser. M_1 and M_4 are the semi-reflective and semi-permeable plane mirrors, M_2 and M_3 are the spherical mirrors. A reference light from a laser light source enters the optical resonator along the light path hole axis on M_1, and then the light beam gets to M_2. By the reflection of M_2, the light beam reaches M_3, and then gets to M_4. Finally, the light beam returns to plane mirror M_1 to continue the next cycle.

Because the reflective orientation of the light beam is unchangeable when it is reflected in any position of a plane mirror, the assembly of two plane mirrors is relatively easy. The essence of the resonator adjustment is to adjust the two spherical mirrors' positions on the optical contact surfaces of the resonator to change the reflective orientation of the light beam, and thus to form a closed-loop optical path, as shown by the dash line in Fig. 1. Moreover, the closed-loop optical path is as close as possible to the center of the optical path hole and the diaphragm, so that the resonator' loss is the lowest. The resonator assembly process is to search for a pair of best reflective points to assemble the two spherical mirrors and thus to achieve the optimal value of optical resonance.

In the process, the movement of the spherical mirrors is accomplished by a micromanipulating mechanism, which is comprised of a coarse positioning stage adopting a parallel structure driven by AC servo motors, and a fine positioning stage driven by piezoelectric ceramics and a gripper. In order to fulfill the optical components assembly accurately, some sensors are used in the process, as shown in Fig. 1. The relative attitude of the spherical mirror and the resonator is obtained by an attitude sensor. In addition, the output light from M_4 is collected by a vision sensor to detect the relative position of the light beam and the diaphragm. At the same time, to get the resonator loss, the output light is collected by a photoelectric signal sensor. Lastly, a force sensor is used to measure the contact force between the spherical mirror and the resonator in the assembly process.

3. Multi-sensor assembly

3.1. *Attitude measurement*

In the optical assembly process, a key issue is to determine the distance and attitude between the spherical mirror and the resonator. There are a number of ways to detect the attitude between two objects,[9–11] such as micrometer gauge, photoelectric sensor, transit instrument, three-coordinates measuring machine, etc. However, these ways are unsuited to resonator adjustment. In the process, the distance error and angle error between the spherical mirror and the resonator should be less than 1 μm and 15″ respectively. To avoid destroying the optical components and ensure the seal ability of the resonator, there must be no other objects to contact the optical contact surfaces of the spherical mirror and the resonator before the assembly. Considering the shape of the optical contact surfaces (the resonator is square, and the spherical mirror is circular), the four corners of the optical contact surface of the resonator can be used to measure the attitude by the contact method. The principle of attitude measuring is shown in Fig. 2. Four linear variable differential transformers (LVDTs) are distributed at the optical contact surface of the resonator symmetrically, and the spherical mirror is located in the center of the four LVDTs. The resonator assembled is fixed in a frame. The four LVDTs are utilized to obtain the distance (z) and attitude (θ_x, θ_y) between the spherical mirror and the resonator.

Only three micro-displacement sensors take effect in the actual assembly process. In order to enhance the integrity of the system appearance, four sensors of symmetrical distribution

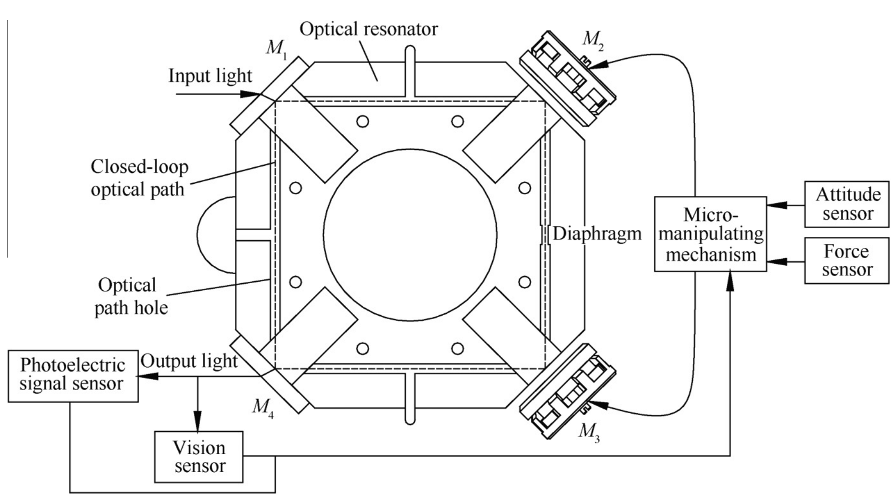

Fig. 1 Schematic diagram of assembly principle.