Research on six-degree-of-freedom calibration system for wind tunnel balances with a collimated laser beam

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A newly-developed six-degree-of-freedom calibration system for the wind tunnel balances is introduced. The frame of the system, the functions and the operating principle of different parts are presented in detail. The system is composed of four parts: the automatically loading subsystem, the automatically resetting subsystem, the data-acquisition subsystem and the measurement subsystem. The results of some cell experiments proved that the system can meet the needs of the present calibration task of the balance. Through further improvement, the system can be also used to calibrate other devices with multi degree-of-freedom and measure the minute shifts, such as the guide rail of machine tool and the assembling of large parts and so on.

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The researchers in the field of pneumatic experiments[1,2] have done many studies on the calibration equipment of balance, especially on the improvement of the load level, the calibration precision, automation and work efficiency. A newly-developed six-degree-of-freedom calibration system of the wind tunnel balance is introduced in this paper. The system is composed of four parts: an automatically loading subsystem, an automatically resetting subsystem, a data-acquisition subsystem and a measurement subsystem. The technique of measuring multi degree-of-freedom shifts real-time is currently a hot research field at home and abroad[3−8]. In the system, the measuring precision of the calibrating head would directly influences the balance calibration precision. Two holographic lenses are first used to measure the position and the attitude of the spatial target. Based on VXI bus techniques, the fully-automatic system has good characteristics such as heavy load, high precision, easy operation and short work time. The results of some experiments have proved that the system can meet the needs of the present calibration task of balance.

Figure 1 is the block diagram of the six-degree-of-freedom calibration system of the wind tunnel balance. According to the requirement of the calibrated balance, the loading subsystem controls 11 AC motors to put different masses and numbers of poises on the balance automatically. The measurement subsystem measures real-time six-degree-of-freedom shifts (linear shift Δx, Δy, and Δz, and angle shift α, β, and γ) of the calibrating head and transmits the signals to the main controlling computer. The automatically resetting subsystem controls 6 servo motors to compensate the shifts. After the automatically loading and resetting have been finished, the signals of calibrated balance will be collected by HP E1413 modules (16-bit A/D converter) through VXI bus. Subsequently, the automatically unloading and resetting will be done till the calibrating head turns back to the original position. During the process, all works are all controlled by the management software of the main controlling computer and can be operated by hand or automatically.

The key function of the automatically loading subsystem is to put precise calibrating load on the balance being calibrated. As shown in Fig. 2, the main controlling computer executes different loading programs and controls 11 three-phase AC asynchronous motors to put different masses and different numbers of poises on the balance by VXI bus and HPE1463 modules. The heaviest one of the clusters of poises is 244 kg, and the lightest one among different clusters are 1, 0.5 and 0.25 kg, respectively.

During the process of loading, the 11 force sensors are used to detect the loads. Their signals are transmitted to the main controlling computer by VXI bus and HPE1413 modules and used to monitor the quantities of poises.

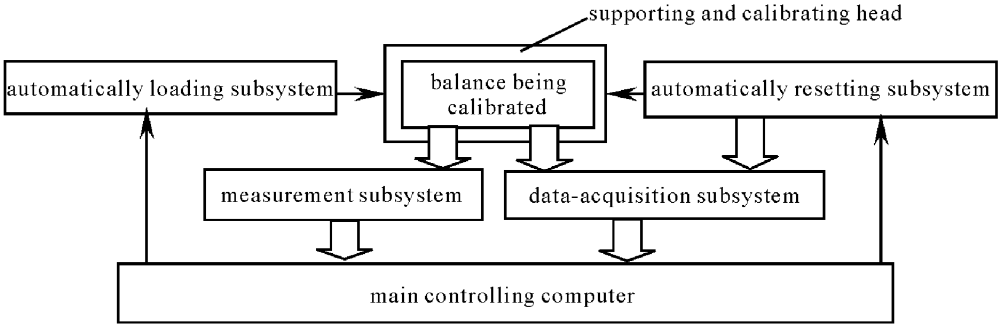

Fig. 1. Block diagram of the wind tunnel balance calibration system.

The precision of poises ensures the load precision. When abnormal conditions occur, for example, the clusters of poises are declining or not loaded to the expected position, the signals can be used as an alarm. The two limiting switches can be used to turn off the motors by force to protect the balance when the main controlling computer intermits or dies.

The main function of the measurement subsystem is to real-time measure six-degree-of-freedom changes of the calibrating head, and to transmit the information to the automatically resetting subsystem to drive 6 resetting servo motors and make the calibrating head return to the original position and attitude.

The holographic lens is used as light-splitting lens. The off-axis sine holographic lens can be regarded as sine grating, the information can be carried by the 0 degree transmitting beam and the 1 degree convergent beam is utilized to perform measurements (the 1 degree divergent beam has been discarded, shown as dashed line in Fig. 3).

As shown in Fig. 3, after the He-Ne laser beam is transformed through collimating and expanding component, it enters into the drift-compensating component to compensate the drift of spatial distribution and energy distribution. The beam is divided into two parts through light-splitter, one of the beams is incident on the holographic lens 1, and the other is incident on the holographic lens 2 by the reflector 1 and 2.

The coordinate system with the center of holographic lens 1 as the origin O (as shown in Fig. 4) is established, where YOZ is the plane of holographic lens, $YO'Z$ is the plane of PSD 1 and UFV is the plane of PSD 2. When the incident beam reaches on holographic lens 1 along the direction with the angles of $\alpha+\Delta\alpha$, $\beta+\Delta\beta$, $\gamma+\Delta\gamma$, it can be divided into three parts. Under the Fresnel approximate condition ($\Delta\alpha \approx \Delta\beta \approx \Delta\gamma \approx 0$), only thinking about the position information carried by beam and ignoring the time-factor, the incident beam reaching on PSD 1 along the original incident direction can be regarded as the extension of the original beam, the shift of the beam center of energy on PSD 1 is just the displacement between the laser beam and the target along the Y, Z directions, that is

$$\Delta y \approx y_B, \quad \Delta z \approx z_B, \tag{1}$$

where y_B and z_B are the shifts of the beam on PSD 1 along Y and Z axes. The incident beam on PSD 2 maintains the information of the original object light. If the beam is convergent, the linear displacement of the beam in any direction and the relative angle (γ) displacement along the X axis could not lead to the relative shift of the focus of the holographic lens. Only when relative angles α and β change, the focus will move on PSD 2. So the movement of focus is associated with the shifts of α and β, that is

$$\Delta\alpha \approx V_{B1}/Z_F, \quad \Delta\beta \approx U_{B1}/\sqrt{X_F^2+Z_F^2}, \tag{2}$$

where V_{B1} and U_{B1} are shifts of the incident beam on PSD 2 along V and U axes, Z_F is the focus length of the holographic lens, X_F is the coordinate value of F in XOY coordinate system. Since another divergent beam (shown as the dashed line in Fig. 3) is the conjugate beam of the convergent beam, it is useless and discarded.

In a similar way, the incident beam on the holographic lens 2 can also be divided into three parts: the beams on PSD 3 and PSD 4 are associated with the linear displacement Δx and the angle displacement $\Delta\gamma$,

$$\Delta x \approx x'_B, \quad \Delta\gamma \approx V'_{B1}/Z'_F, \tag{3}$$

where x'_B is the shift of the beam on PSD 3 along X axis, V'_{B1} is the shift of the beam on PSD 4 along V axis, and Z'_F is the focus length of the holographic lens 2. The 3rd beam is useless and discarded.

According to the principle mentioned above, the system for cell experiment was established in laboratory. Measuring target, 10 mW He-Ne laser, the collimating and expanding system are all fixed to the working table.

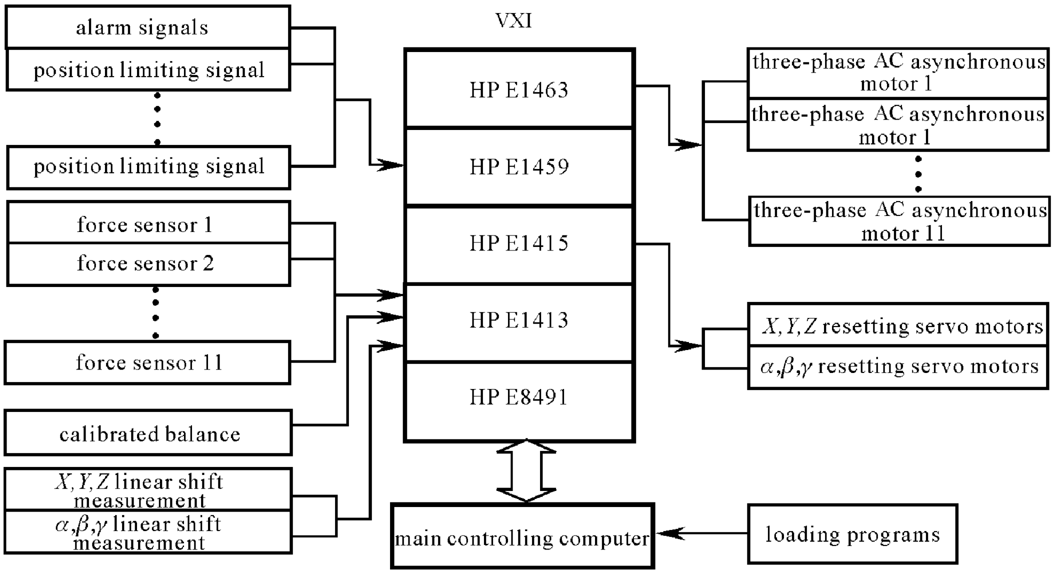

Fig. 2. Controlling diagram of the wind tunnel balance calibration system.

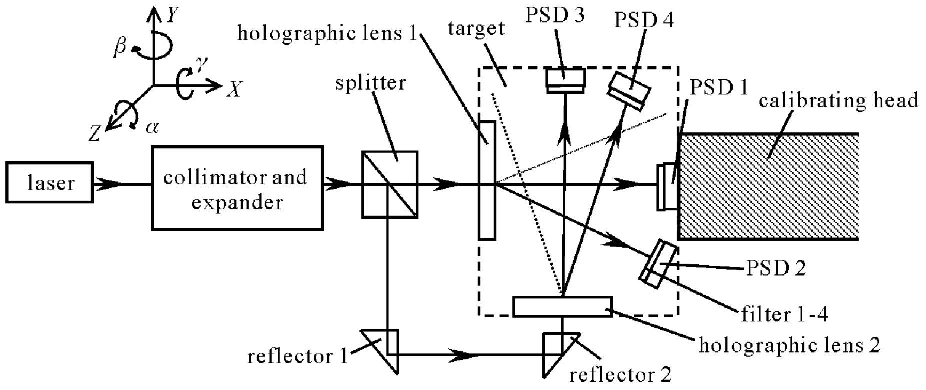

Fig. 3. The schamatic of six-degree-of-freedom measuring subsystem.

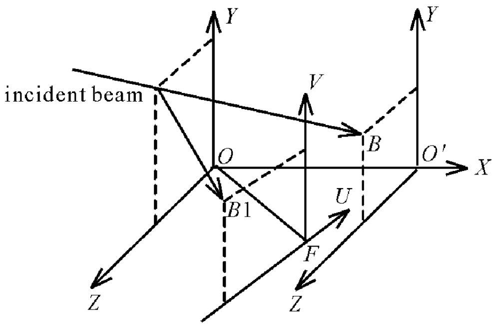

Fig. 4. The coordinates of incident laser and measuring system.

The distance between target and laser source is 1.5 m, the focus length of holographic lens is 200 mm, and the resolution of the PSD is 1 μm. The cell experiment was done many times in different position. The result showed that the resolution of linear displacement is 1 μm and the resolution of angle displacement is $1''$.

The newly-developed six-degree-of-freedom calibration system for wind tunnel balances has many merits such as high precision, high automation, easy operation and stable performances. The results of experiments proved that the system can meet the needs of the present calibration task of balances. After further improvement, the system can also be used to calibrate the other devices with multi-degree-of-freedom and measure the minute shifts, for example, the guide rail of machine tool and the assembling of large parts.

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