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Calibration method of HLS's sensor used in SSRF

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Abstract The site of Shanghai Synchrotron Radiation Facility (SSRF) is of complicated geological conditions, and a system to monitor the uneven subsidence of foundation and key parts (different kinds of magnets) of the accelerators is a necessity. Considering actual conditions of the accelerator structure and the assembling place, a new type of sensor of hydrostatic levelling system (HLS) has been designed. In order to obtain the required measurement accuracy, every HLS's sensor was strictly calibrated. In this paper, we introduce the special calibration method to establish the HLS. The method has been used in the calibration for vessel sensor for SSRF.

Key words Hydrostatic levelling system (HLS), Calibration, Charge-coupled devices(CCD)

CLC number TL346.5

1 Introduction

The Shanghai Synchrotron Radiation Facility (SSRF), a low emittance third-generation light source, consists of a 150 MeV linac, a booster, a 3.5 GeV storage ring of 432 m in circumference, and the beam lines and stations[1]. With its site at the confluence of canals in Pudong, where the geological condition is complicated, the uneven subsidence of the foundation and the critical parts must be monitored[2].

A hydrostatic levelling system (HLS) for high accuracy levelling between two points hundreds meters apart will be used to monitor vertical displacement of the foundation and the supports of the insert devices[3]. Based on principle of the communicating vessels, the HLS uses the free surface of water or other liquid as an absolute measurement reference. Each point (vessel) of the network has a sensor to measure the vertical distance between the mark and the altimetry reference plane. There are different methods to measure and record changes of a liquid surface. In this paper, we report a newly developed HLS with charge-coupled devices (CCD) to measure and record the upper surface of a liquid for SSRF.

2 CCD HLS prototypes

Fig.1 shows the cross section of the HLS vessel. The mark bar connected via a stick to the float moves up and down with the liquid surface. A bundle of parallel lights shines on the bar and produces a shadow band on the acceptance widows of CCD.

Fig.2 shows components of the light and CCD system. A TCD2901D type CCD (Toshiba, Japan) is used. The high sensitivity and low dark current CCD has 10550×3 image sensors. It has a drive circuit and clamp circuit, powered at 12 V and operated by 5V pulse. The image sensing element size is 7 μm × 7 μm × 7 μm. The center of gravity method is used to obtain a higher sensor resolution[4]. This calculation code is embedded in the signal circuit of every sensor. The sensor resolution can be < 1μm.

The distance between the highest and lowest liquid surface determines the measurement range, which is ±5 mm for this HLS.

Water is chosen as the working liquid. A big problem, however, is that the water volume changes

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with temperature[5]. To account for temperature difference between the vessels, a temperature sensor in absolute resolution of 0.1°C and relative resolution of 0.5% is used to measure the water temperature. The vessel wall thickness at the temperature sensor deployment is minimized deliberately to facilitate the water temperature measurement[6].

Fig.3 is a vessel sensor. The HLS sensors are connected with a data acquisition device with its own clock. It communicates with a PC via RS485 interface.

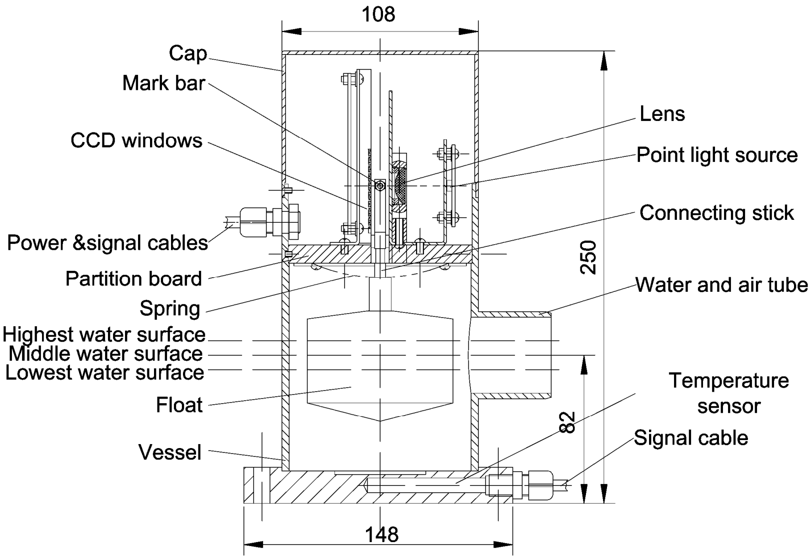

Fig.1 Cross section of the HLS vessel.

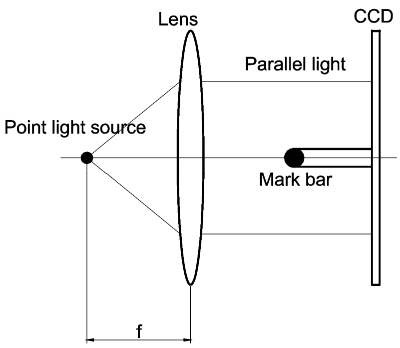

Fig.2 Light, mark bar and CCD system.

Fig.3 Photo of the vessel.

3 Calibrations

3.1 CCD calibration

The calibration includes the outputs of both CCD and vessel. Although performance of an HLS is determined by every part of the system, the CCD calibration can test its resolution and linearity, which affect performance of the HLS system.

A Renishaw10 laser is used to calibrate the CCD (Fig.4). A connecting stick and retroreflector are fixed on the table movable horizontally by screws and connecting parts. The connecting stick is aligned with the laser beam to eliminate the Abbe error during measuring. Test data obtained by moving the table in about 1 mm increment for six successive steps (6 mm), and moving it back in the same way, are shown in Fig.5.

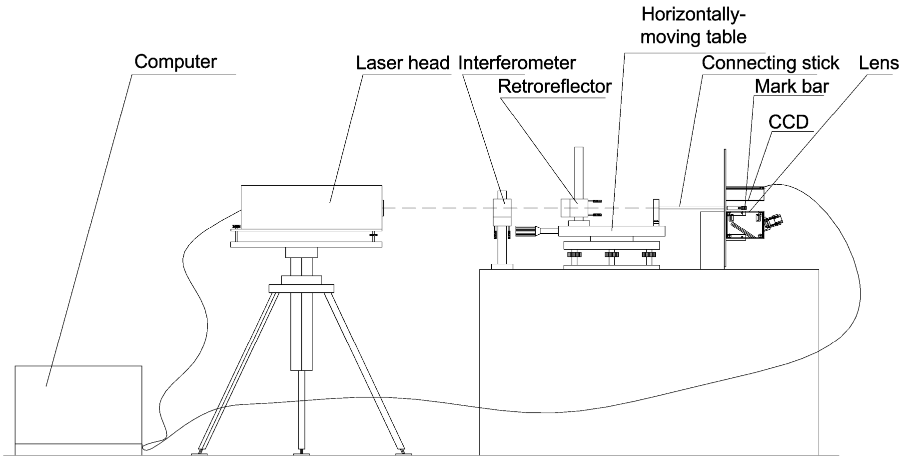

Fig. 4 Layout of the CCD calibration system.

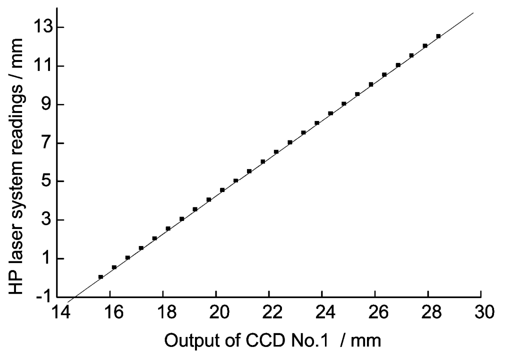

Fig.5 Calibration results of CCD No.1.

The fitting SD of the output of every CCD and Renishaw 10 readings obtained by linear fitting is <0.001 mm, which is less than the allowed error of 0.005 mm.

3.2 Calibration of vessel sensor

The calibration can be done by controlling the elevation of one vessel with a laser system to measure the change in the elevation, and comparing it with output of the vessel sensor. But in such a method, or similar approaches, two or more vessel sensors should be used, and the calibration result would be affected by more system factors. We designed a system that calibrates just one vessel sensor by comparing the laser readings to the sensor output. Fig.6 shows the principle of the system.

The upper part of the vessel sensor is fixed on a connecting board, which in turn is fixed with the spindle of CNC machining centre which can move up and down in 2 μm paces precisely. The float moves freely with the surface of water of suitable depth in a container. As the spindle moves up and down, and so does the connecting board, the fixed upper part moves the same distance. In this way, the real working status of the vessel sensor can be reflected. At the top of the vessel, a retroreflector of the laser measurement system is fixed. The interferometer is fixed on a fixing board. And moving distance of the vessel is measured by the laser system. Readings of the laser system and the sensor outputs are compared to calibrate the vessel sensor.

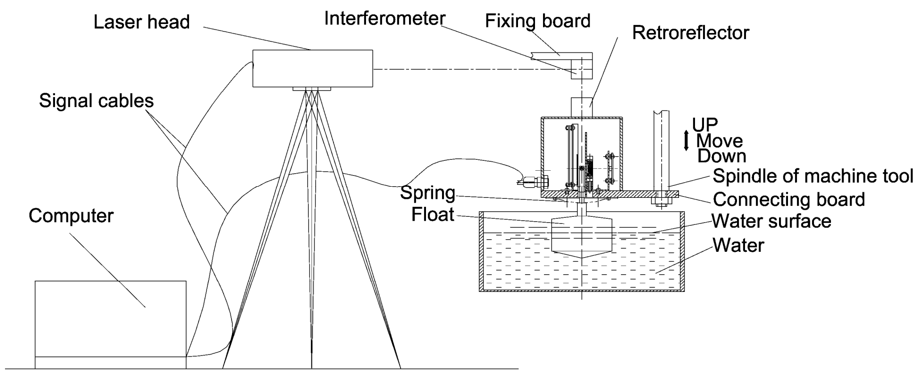

Fig.6 Calibration system for one vessel.

Fig. 7 is the fitting line based on the calibrating data of one vessel sensor. The data can be fitted by

$$Y = -1.0045\,X + 39.99316,$$

with an SD of ±0.02127 mm.

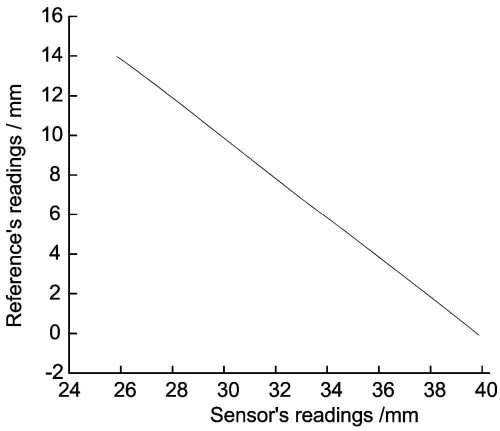

Fig.7 Fitting line.

To correct the non-linearity of the sensor output over ±5 mm range, a forth degree polynomial curve was used to fit the curve:

$$Y = -65.09131 + 12.06008X - 0.60445X^2 + 0.01234X^3 - 0.00009X^4.$$

And the standard deviation is SD = ±0.00726 mm.

4 Conclusion

The presented calibration method has been proven to work well. By this method, we can calibrate the vessel sensors one by one directly, and get the fitting formulas for each sensor. This method has been used in the calibration for vessel sensor for SSRF. After calibration, they were assembled in the SSRF to establish the HLS system.

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