SOME EXPERIMENTS ON A NEW HYDROSTATIC LEVELLING SYSTEM DEVELOPED FOR BEPCII*

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Abstract. The charged coupled device (CCD) is widely used in measurement and survey engineering. A new type of Hydrostatic Levelling System (HLS) based on the CCD technology has been developed for the possible real time altimetric control in BEPCII. In this paper some experimental results on the HLS are shown, especially concerned with some influencing factors of the system.

Key words: CCD, hydrostatic levelling system, HLS, calibration, correction of non-linearity, straight line fit

1. INTRODUCTION

The major upgrade of the Beijing Electron Positron Collider (known as BEPC II), the largest scientific facility proposed in China has been carried out in an all round way since last year. The physics goal of BEPCII is the precision measurements of charm physics and search for new particles and phenomena. The upgrade is expected to be finished by the end of 2006, and the physics running is scheduled by spring 2007.

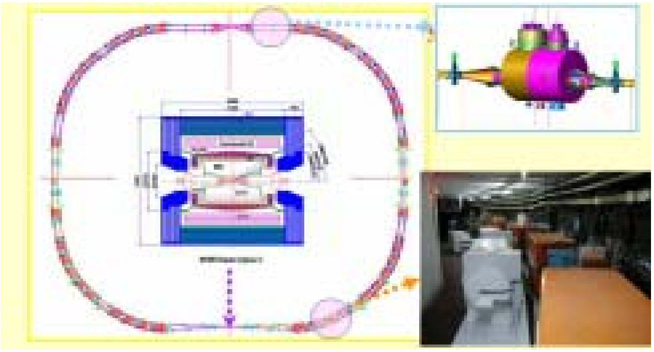

Fig.1 General layout for BEPCII storage ring

BEPCII is a double-ring collider within the existing BEPC tunnel with width of about four meters. Fig.1 shows the BEPCII layout. It is very difficult for the work of alignment and adjustment to be conducted in so crowded situation after the double-ring installation. So some

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automatic measurement and adjustment methods were considered during the project design, which include the Hydrostatic Levelling System (HLS) concept in the automatic altimetric measurement of the machine.

HLS measuring system has been widely used in international accelerator laboratories and other civil engineering. Although HLS has the same general principle of communicating vessels, there are different kinds of methods to measure and record the changes of a liquid surface. In this paper a new Hydrostatic Levelling System developed for the BEPCII is proposed. In this case the charge couple devices (CCD) are used to measure and record the upper surface of a liquid.

2. CCD HLS PROTOTYPES

Development of this new type of CCD HLS started in March 2003.Colaberating with Institute of Crustal Dynamics of CEA, China; we got the working prototype units for testing and calibration in May 2004. Fig.2 shows the cross section of the HLS vessel.

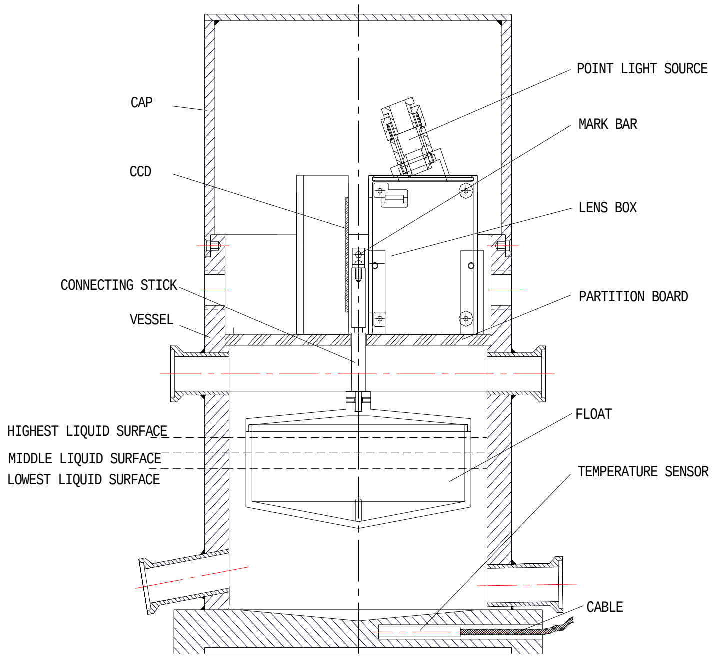

Fig.2 Cross section of the HLS vessel

The float moves up and down with the height of the surface of liquid. And the mark bar moves up and down too along with the float connected through connecting stick. A bundle of parallel light shines on the bar and it will produce a shadow band on the acceptance widows of CCD. Fig. 3 shows the principle of the light and CCD system.

TCD2901D type CCD, production of TOSHIBA COMPANY, Japan, is chosen in this HLS. It is a high sensitive and low dark current 10550 elements×3 line CCD image sensor which includes drive circuit and clamp circuit, and is operated by 5V pulse and 12 V power supply. The image sensing element size is 4 μm by 4μm on 4μm centres. So in order to get higher resolution of the sensor, the signal output by the HLS sensor is the mean of 25 measurements taken in one second.

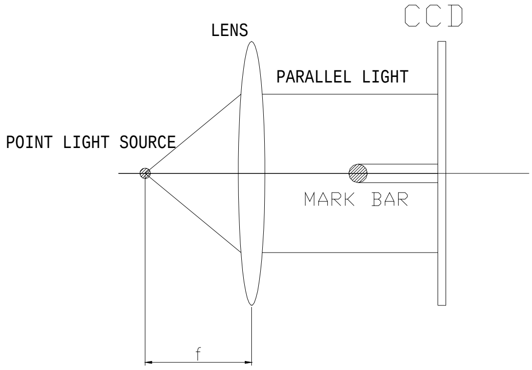

FIG. 3 Light, mark bar and CCD system

The distance between the highest and lowest liquid surface determines the measurement range. The measurement rang of this type of HLS is 10 mm.

Water is chosen as the working liquid because of safe, inexpensive and its well-known properties. But because water has relatively serious coefficient of dilation along with temperature changing, the influent factor of the temperature difference between vessels must be adjusted in the altimetric measurement. So, temperature sensor of which absolute resolution is 0.1oC and relative resolution is 0.05oC is used to measure the temperature of water in vessel. The thickness of the vessel perpendicular to the temperature sensor probe centred on the vessel is minimized deliberately in order to get water temperature more directly. Here the authors would like to thank Daniel Roux and D. Martin, ESRF, for their papers [2] provide us some ideas during the vessel structure designs. Fig. 4 shows the photo of the vessel and upper part in it.

Fig.4 Photo of vessel and the upper part in the vessel

In a system of more then one vessel, all the HLS sensors are connected with a data acquisition with its own clock where the data are stored, and which can communicate with PC via RS485 interface.

3. CALIBRATION

Calibration includes the outputs of CCD and vessel. HLS accuracy is mainly determined by the unit of vessel, which is a system containing float, water, etc. besides CCD. But the calibration of CCD can test its resolution and linearity, which influence the accuracy of HLS system.

3.1. Calibration of CCD

HP 5528A Measurement Laser System is used to calibrate the CCD. Fig. 5 shows the CCD calibration system. The connecting stick and retroflector are fixed on the horizontally moving table by screws and connecting spare parts. The axle of the connecting stick and the laser beam are on the same line so as to eliminate the Abbe error during measuring. Moving the table forth and back, we get the reading of the laser system and the sign from the CCD. The laser measurement reading is the calibration datum.

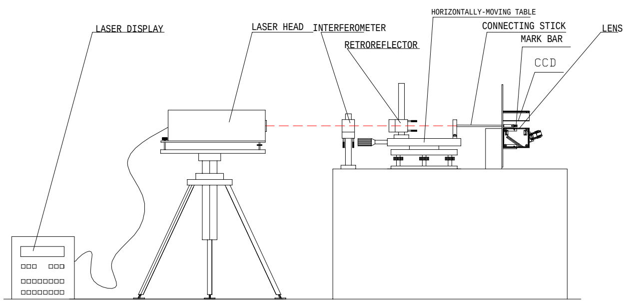

Fig.5 Layout of the CCD calibration system

The preliminary calibration was performed in May 2004. Turn the screw to make the horizontal moving table move in a direction in six successive about one mm increments for a total six mm, and then make table move back by six successive about one mm increments and finally arrive to its original location. Fig.6 shows one example of calibration results of the CCD.

By linear fitting, the fitting SD=0.0063mm of the output of CCD and HP readings, which is better then 0.01mm, the allowed error.

The resolution feature of the CCD is 4μm and we hope the resolution is 2μm by taking the signal output of the mean of 25 measurements taken in one second. We check the resolution by taking the same steps as the

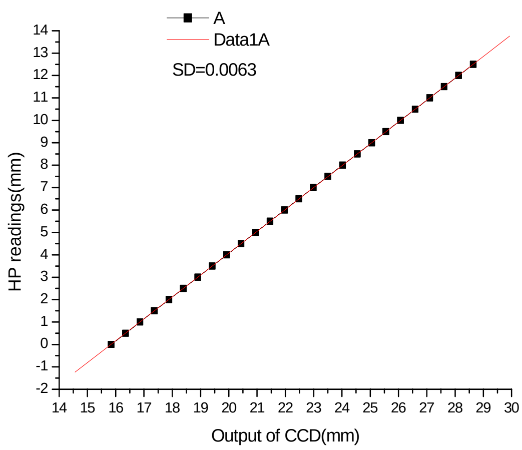

Fig. 6 Calibration curve of CCD

calibration but the range is 0.02 mm and the increment is 0.001 mm surveyed by HP Laser Measurement System. Table.1 shows the result, and from which we can get the hoped resolution better then 2μm.

Time	HP	CCD	Time	HP	CCD	Time	HP	CCD	Time	HP	CCD
18:55:40	4.9996	20.948	19:01:20	5.0097	20.956	19:07:20	5.0199	20.968	19:11:50	5.0096	20.956
18:56:40	5.0005	20.948	19:02:10	5.011	20.959	19:07:40	5.0193	20.968	19:12:10	5.009	20.956
18:57:10	5.0015	20.948	19:02:30	5.0115	20.96	19:08:10	5.0183	20.967	19:12:30	5.0081	20.956
18:58:00	5.0026	20.948	19:02:50	5.0129	20.96	19:09:00	5.0173	20.964	19:13:00	5.0069	20.953
18:58:20	5.0034	20.949	19:03:20	5.0137	20.961	19:09:20	5.016	20.964	19:13:40	5.006	20.952
18:58:50	5.0046	20.952	19:03:50	5.0146	20.963	19:09:50	5.015	20.963	19:14:10	5.0045	20.952
18:59:10	5.0057	20.952	19:04:30	5.0156	20.964	19:10:10	5.0142	20.962	19:14:30	5.0039	20.951
18:59:50	5.0066	20.952	19:05:00	5.0166	20.964	19:10:40	5.0127	20.96	19:15:00	5.0031	20.95
19:00:30	5.0079	20.955	19:05:50	5.0178	20.965	19:11:00	5.0122	20.96	19:15:30	5.0019	20.948
19:00:50	5.0086	20.955	19:06:50	5.019	20.968	19:11:20	5.0109	20.959	19:15:50	5.0007	20.948

Table 1 from the output of CCD to check the resolution (mm)

3.2. Calibration of vessel sensor

Several methods for calibrating the units of vessel are designed. First of all by controlling the elevation of one vessel in a system of two vessels. HP 5528A Laser Measurement System is used to measure the change of the elevation, which is changed by turning the large central screw. But after some experiments we found that the uneven screw pitch made the HP readings do not reflect the true elevation of the vessel. So we use the second method instead of the first one, which is by adding a known volume steel lump. The first method just is used as the resolution test in a little elevation change of the vessel.Fig.7 shows the calibration system.

Fig.7 Calibration of a system of two vessels

The steel lump is a cylinder of Φ21mm×10mm. And the inner diameter of the vessel is 126mm.So in a system of two vessels, one of the steel lump is added in the water of a vessel will make the water level raise about 138.89μm.We added five lumps one time and the water level would raise 694.445μm in each vessel. Fig.8.shows the calibration result.

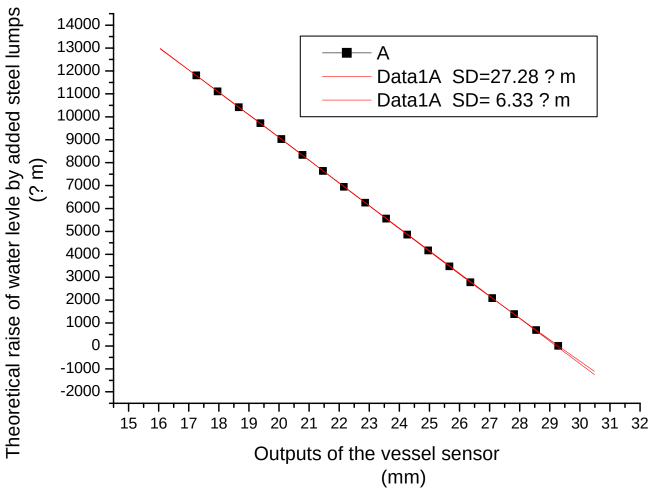

Fig.8 Calibration curve of vessel

After linear fitting of the data we got standard deviation of the fit is 27.28μm.In order to correct the non-linearity of the sensor output over the range of 10mm(the readings of output of the sensor from 17 mm to 28 mm), we used a third degree polynomial curve to fit the measurement curve. And the result of SD is better then 0.02 mm.

3.3. Experiments about nine-vessel HLS system

After finishing all calibration of the vessels, we got different polynomial regression formulas for each one. Then we establish a nine-vessel HLS system to test the calibration result.

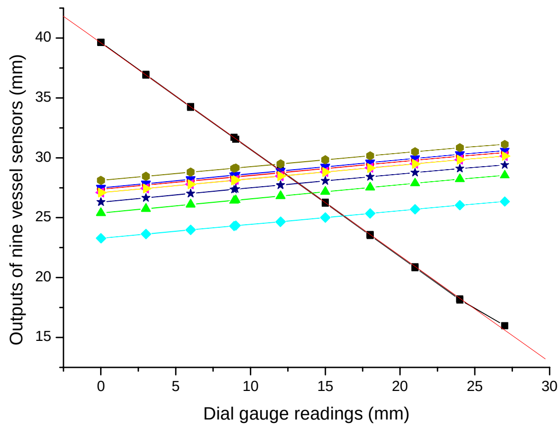

Fig.9 Test of nine-vessel system

In this system we raised and lowed the No.1 vessel by 3 mm increments. Then the water level of No.1 vessel would go down or up of 3*(9-1)/9=2.6667 mm a step. Otherwise the water level in other vessels would go up or down of 3/9=0.3333mm a step. Fig.9 Shows the test result.

Here we used dial gauge instead of HP Laser Measurement System to directly measure the elevation change of the No.1 vessel. In order to test other vessel sensors in more scale the elevation change margin of No.1 vessel exceeded its range and could not get a correct output at the two ends. The SD of outputs of each vessel sensor is less then 0.02 mm, which is our technological target for this type of HLS.

4. INFLUENTE FACTOR OF TEMPERATURE

Although overall change in the temperature in HLS has strong effect on the variation of the average water level, it has no effect on the measurement result of the elevation change.

A temperature difference among vessels has a severe influence on measurement results. Fig. 10 shows the relation between water density and its temperature. The relation between them is not linear.

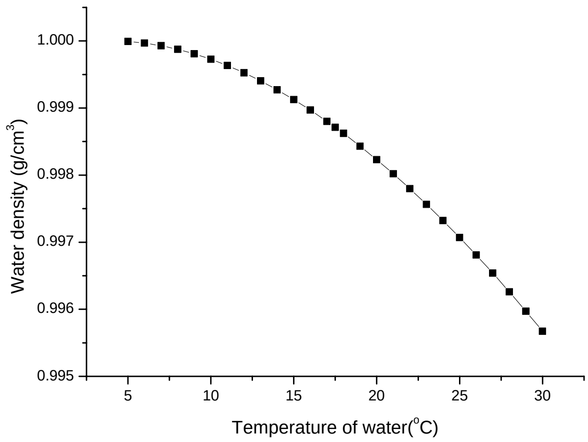

Fig.10 relation between water density and its temperature

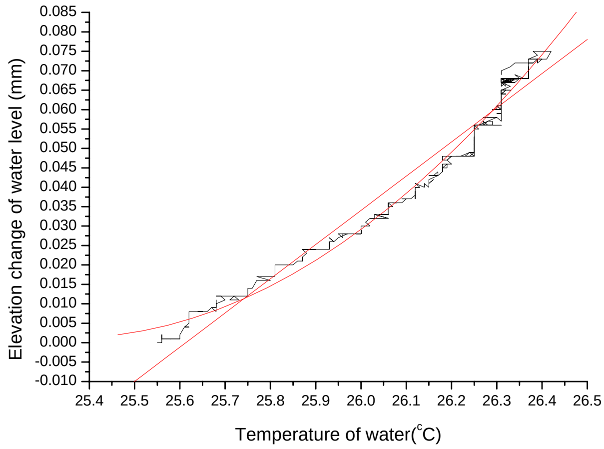

Fig.11 elevation change related to temperature

In this type of HLS, the water height in each vessel is about 7 cm. We did some experiments to find the relation between the outputs of vessel sensor and temperature changes and then get the correction formula. Fig.11 shows this relation in a relatively narrow temperature change range included in our measurement environment. By using polynomial fitting (generally second degree), we got the correct formula with temperature as the variable for each of the vessels.

By the way, during the experiments, we first used the heating belt to heat the vessel by covering it on the exterior, meanwhile recorded the output of the temperature and vessel sensor. But the result was not acceptable because the temperature changing rate was too fast, the water and other parts in the vessel had no time to get thermal equilibrium. So the test was failure. Then we turned to record the output of the temperature sensors and vessel sensors for a long time without changing the elevation of the vessel, when the temperature changed along with the measurement environment.

5. CONCLUSION

There are many factors influencing the accuracy, resolution etc. of HLS. So many technological precautions are widely used in HLS to get higher accuracy, higher resolution and higher reliability. For this type of CCD HLS, we tested on it just from April this year and we have lots of jobs to do. For example, if the light system can get better parallel light the accuracy and reliability will be better. Recently the accuracy of the HLS better then 0.02 mm is suitable enough for the BEPCII elevation surveillance. We will do more detailed test on this HLS and develop it in its features along with the technology development and technological requirement of BEPCII and other machines.

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