A Real-time Dynamic Deflection Measurement Method using Dual Camera for Lifting Device Dynamic and Static Load Test

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Abstract. In the process of deflection measurement for lifting device dynamic and static load test (DSLT), the traditional measurement method has some obvious problems, such as complex test process, slow measurement speed, poor accuracy, low efficiency, and difficult dynamic measurement. Therefore, a real-time binocular vision method for measuring deflection in the lifting device DSLT is proposed. The results of verification show that the method can realize the real-time and fast deflection measurement in the lifting device DSLT, and has the advantages of non-contact, high precision and dynamic measurement. Compared with the traditional methods, the method proposed in this paper is simple, universal and easy to implement.

1. Introduction

Lifting device is a special device, which is usually used to connect the crane with the product and meet specific lifting requirements. Usually, the structure of lifting device is mainly composed of lifting device body, rings, sling and lug. The main body of most lifting devices is rigid beam. When a beam is forced to bend, it will produce displacement, which is called the deflection of beam. According to the design or test specification of lifting device, the DSLT is a test item that must be carried out in the process of acceptance of lifting device. In the process of static load test and dynamic load test, there are strict regulations on the beam deflection in the design or test specification of lifting device. According to the different levels of lifting device, the beam deflections should not exceed l/300 ~ l/1000 (l is the span between the lifting points at both ends of lifting beam). Deflection is one of the main indexes to judge whether the lifting device is qualified and whether the safety factor is up to the standard [1-2].

At present, the deflection measurement method of lifting device mainly includes steel ruler method, hand-held laser rangefinder method, strain calculation method, general photogrammetry method, etc. Among them, the steel ruler method is a steel ruler-based measuring approach, which uses steel ruler to measure, and obtains the lifting device deflection according to the proportion conversion. This method has poor measurement accuracy and poor safety, and the dynamic deflection cannot be measured using the steel ruler method. Hand held laser rangefinder method is a laser-based measuring...
approach, which uses hand-held laser rangefinder to measure the absolute height of the lifting point and the center point of the main structure of the lifting device before and after loading, which can calculate the corresponding deflection. This method has poor measurement accuracy and cannot measure the dynamic deflection [3-4]. The strain calculation method is a strain-based measuring approach, which uses the deflection equation in the material mechanics and the surface strain to calculate the deflection of beam. This method is indirect and the measurement accuracy is difficult to evaluate. The general photogrammetric method is a vision-based measuring approach, which adopts single camera close range photogrammetry, and obtains the deformation by solving the photos. Due to the poor pertinence, long preparation time in the test process, this method shows slow measurement speed, slow data acquisition, complex calculation and low efficiency, which is difficult for dynamic deflection measurement [5-6].

In view of the shortcomings of traditional measurement methods, a high-precision, simple and general method for measuring the deflection of lifting device is proposed in this paper, which is based on the design method of hanging follow-up, the design of telescopic vision field adjustment, the dynamic baseline measurement and the calculation mode of motion coordinate system under the condition of large motion space.

2. Real-time dynamic deflection measurement method

In the process of deflection measurement for lifting device DSLT, the traditional measurement method has some obvious problems, such as complex test process, slow measurement speed, poor accuracy, low efficiency, and difficult dynamic measurement. Therefore, a real-time binocular vision method for measuring the deflection of lifting device is proposed to realize the real-time, fast and high precision measurement of the beam deflection in the DSLT of the lifting device. The main principle of this method is to obtain the visual image of the measured object using two dynamic measuring CCD, and calculate the three-dimensional coordinates of the measured object according to the principle of light triangle intersection. The technical schemes for real-time binocular visual deflection measurement are as follows:

To solve the problem that the CCD vision field can effectively follow the tested area of the lifting device during the DSLT, and at the same time, no additional load is imposed on the lifting device and no additional error is added to the test, the hanging follow-up design method under the condition of large moving space is introduced. The design method is applied to realize the follow-up of vision measuring CCD and lifting device in the process of DSLT, which ensure that the measured area is always in the public vision field of binocular vision measuring system, and maintain the best distance. Furthermore, in order to realize the real-time measurement of dynamic and static deflection of lifting device with different configurations and scales, the design of telescopic vision field adjusting device is proposed. By adjusting the distance between the visual measurement CCD system and the measured surface of lifting device, the problem of universality has been solved. At the same time, in order to keep the relative relationship between the internal and external parameters of the two CCDs consistent with the calibration state before the test, the dynamic baseline measurement method is proposed, which ensure that there is only rigid displacement in the measurement baseline during the DSLT, and the relative pose of the two CCDs does not change, so as to achieve high-precision measurement. Considering the large moving range and changeable state of the lifting device during the DSLT, the usual static coordinate system method is difficult to meet the dynamic and high-precision measurement requirements, the dynamic coordinate system method is proposed. Based on the general characteristics of lifting device (Figure 1) and the binocular vision measurement method, the three-dimensional coordinate value of the measured mark point in the dynamic coordinate system is measured through establishing the dynamic coordinate system in the process of the dynamic and static test, and the real-time change of the relative position relationship of the measured target point is solved by using the means of multi-target point plane construction, so as to realize the real-time solution of the deflection.
The technical scheme proposed in this paper is realized as follows:

The measurement system described in this real-time binocular vision method is as shown in Figure 2, which includes the CCD1, the CCD2, the image acquisition controller, the control line, the computer, the target a, the target b, the target c, the target d and the target e, the measuring hoisting set, the telescoping handle, the top connection plate, the calibration scale, the test specimen and the loading device. The test specimen comprises the suspension beam, the lower sling, the upper sling and the clump weight. The lower sling is connected with the clump weight, the upper sling and connector is connected with the lower sling, the lower end of the sling at the upper part of the beam is connected with the upper lifting point of the beam through the connector, the upper part is connected with the lower hook of the top connecting plate, and the upper end of the top connecting plate is connected with the dynamic and static load test loading equipment of the lifting device through the hook.

In the process of DSLT of lifting device, the moving coordinate system with target e as reference point is established, and the image information of measurement target a, measurement target b, measurement target c and measurement target d is collected dynamically, the real-time three-dimensional coordinate changes of the measuring targets a, b, c and d in the moving coordinate system are obtained by the image processing computer, and the deflection of the beam at different times is obtained by calculating the relative coordinate changes of each target point.
3. Implementation cases

3.1. Test conditions

3.1.1 Static load test. The test is carried out at room temperature. The static load test load is 125\% (1875 kg) of the rated load. The loading procedure of static load test is as follows: lifting 200 mm above the ground, holding for 30 minutes, and measuring the deflection value every 10 minutes.

3.1.2 Dynamic load test. The dynamic load test is carried out on the basis of passing the static load test. The dynamic load test load is 110\% (1650 kg) of the rated load. The dynamic load test loading procedure is as follows: lifting 200 mm above the ground, simulating translation 3 times, simulating lifting 3 times. In the process of translation and lifting, simulate braking. During the test, the deflection of the lifting device is measured in real time.

3.2. Implementation procedure

The implementation procedure of the real-time binocular vision method for measuring deflection is as follows:

- Step 1: The test specimen installation. Connect the beam, the sling, the accessory connector and the counterweight as shown in Figure 2.
- Step 2: The top connection plate installation. Connect the lifting points of top connecting plate, the loading device and the lifting device as shown in Figure 2.
- Step 3: The CCD hanging device and telescopic hanging rod installation. The upper ends of the two telescopic suspension rods are respectively connected with the reserved interfaces at both ends of the top connecting plate, and the lower end of the telescopic suspension rods are connected with the CCD hanging device.
- Step 4: The visual measurement system installation and connection. The measuring targets are pasted at the position shown in Figure 2; the CCD1 and CCD2 are respectively installed at both ends of the CCD hanging device, and the image acquisition controller is installed in the middle of the CCD hanging device; the CCD1, the CCD2 and the image acquisition controller are connected with the image processing computer through the control and transmission wire.
- Step 5: The height of the hanging device adjustment. By controlling the loading device, the lifting device moves upward until the beam is off the ground, and the lower sling is not stressed, that is, the counterweight is not off the ground and is not affected by the lower sling. Simultaneously, by adjusting the length of the telescopic suspension rods, the CCD hanging device installed with CCD1, CCD2 and image acquisition controller can be adjusted to the appropriate height for visual measurement.
- Step 6: The CCD orientation and fixation. Adjust the vision field angle of ccd1 and ccd2 to ensure that all targets at the lower lifting point and the lower center of the beam can be covered by CCD1 and CCD2.
- Step 7: Calibration. The calibration ruler is used to calibrate the internal and external parameters of the vision measurement system.
- Step 8: The initial image acquisition. After the calibration, the image acquisition controller is controlled by the image processing computer to obtain the initial images of all the target points in the unloaded state.
- Step 9: The dynamic and static loading test. By controlling the loading device, the DSLT procedure of the lifting device is started.
- Step 10: The image acquisition. During the DSLT of the lifting device, the image information of all targets under different states of the tested object is obtained through multiple shooting.
- Step 11: The 3D coordinate calculation of target point. Through the image processing computer, the images in different states are calculated to obtain the three-dimensional coordinates of the target points at different times.
• Step 12: The data processing and deflection calculation. According to the three-dimensional coordinates of the targets under different loading conditions, the deflection of the lifting beam is calculated.

3.3. Test results and analysis

3.3.1. Static load test. Figure 3 is the deflection measurement results of static load test. It is found from Figure 3 that in the process of static load test, the deflection values of beam 1 measured by this method in 10 min, 20 min and 30 min are 0.073 mm, 0.076 mm and 0.080 mm respectively, and the average deflection value is 0.076 mm; the deflection values of beam 1 measured by traditional binocular photogrammetry method in 10 min, 20 min and 30 min are 0.065 mm, 0.082 mm and 0.069 mm respectively, and the average deflection value is 0.072 mm. The results show that the deflection of beam 2 in 10 min, 20 min and 30 min is 0.071 mm, 0.074 mm and 0.078 mm respectively, and the average deflection is 0.074 mm; the deflection of beam 2 in 10 min, 20 min and 30 min is 0.068 mm, 0.079 mm and 0.067 mm respectively, and the average deflection is 0.071 mm. By comparing and analyzing the measurement results of this method and conventional binocular vision measurement method, it can be concluded that this method proposed in this paper has higher accuracy and smaller discreteness.

3.3.2 Dynamic load test. Figure 4 shows the deflection measurement results of dynamic load test. It can be seen from Figure 4 that: 1) the real-time dynamic deflection of the two beams of the tested lifting device is effectively measured by the method proposed in this paper, which shows that the measurement method proposed in this paper can realize the real-time measurement of the dynamic deflection. 2) In the process of dynamic load test, the maximum deflection values of suspension beam 1 and beam 2 are 0.084mm and 0.082mm respectively. Due to the braking overshoot, although the load of the static test is greater than that of the dynamic test, the maximum deflection values of suspension beam 1 and suspension beam 2 in dynamic load test are greater than that in static load test. This shows that it is necessary to carry out real-time dynamic measurement of the suspension beam deflection in the process of dynamic load test, and the deflection measurement of static load test cannot replace the deflection measurement of dynamic load test.

4. Conclusion
In view of the shortcomings of traditional measurement methods applied to the deflection measurement for lifting device DSLT, a real-time binocular vision method for measuring the deflection of lifting device is proposed, and related experiments are designed in this paper. The results of verification shows that this method can realize the real-time and fast deflection measurement in the
DSLTS of the lifting device, and has the advantages of non-contact, high precision and dynamic measurement. Compared with the traditional methods, the method proposed in this paper is simple, universal and easy to implement. The problem of vision field coverage and the relative position relationship between moving targets in large moving space are solved. The telescopic vision field of adjustment design is employed to overcome the problem of universality. The method is suitable for the related DSLTs of other similar structures.

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