The Measuring Instrument of Plumb Coaxial Error for Long-distance Orifices Based on Laser Collimation

B Liu and M Y Yu

Mail box140, Harbin University of Science & Technology, Xuefu Road 52, Harbin, Heilongjiang, China

E-mail: lb0303@263.net, yumengying1314@163.com

Abstract. Introduce the measuring instrument of plumb coaxial error for long-distance orifices which is according to the measuring requests of Flange Place of experiment fast neutron reactor in nuclear power equipment and designed by combining the laser collimation technique and CCD imaging technique. The measuring instrument constructs the plumb line with utilizing the characteristic of laser and making the CDD as imaging screen, and the line is regarded as the datum line in measurement and used for measuring coaxial error of the large orifices’ manufacture and assemblage under plumb state. Angle resolving power is: 0.3”; displacement resolving power is: 0.02mm; respective degree of uncertainty of measurement results are: 0.1” 0.01mm. The paper detailed introduces the idiographic design principle and measure method of the measuring instrument, and analyzes the measure error. It is applied to measure the precision of manufacture and the coaxial error of assemblage of the large or heavy pipe casting equipment.

1. Introduction

The measurement of coaxial error is always one of the most basic and indispensable measuring items. So, it attracts different countries’ scholars and a lot of research, the research findings is widely applied to measure the precision of machine parts’ manufacture and assemblage. The measurement of coaxial error is also an indispensability measuring item of different measuring instrument, the measure precision is regarded as a guide line weighs the performance of instrument or equipment. But, in the industry production and manufacturing, the large or heavy pipe casting equipment also has higher demands of plumb in holistic configuration and assemblage. For instance, the measurement of coaxial error among the four of Flange Place, oriented trepan boring, mimic panel and faucet of experiment fast neutron reactor not only has demands for prodigious installation dimension and high assemblage precision, but has special demands for no move and deflection swing under the plumb placement. According to these requests, it needs keeping plumb placement in different assemblage and joining process, and finishing the measurement of coaxial error for large scale orifices in the plumb placement.

Because of the large diameter of basic hole of measured hole and large distance between every two holes, the pipe casting with large scale orifices is usually be measured with autocollimator. By its characteristics, laser is widely used as collimation light source. As for the measurement of coaxial error, the Qinghua University [1] and Beijing Information Science & Technology(Beijing ) [2,3], who have good research, all use laser as collimation light source and have good experiment data, the
practicability and precision of equipment are also greatly improved. The system in the paper which combines the measure of plumb of pipe casting and the measure of coaxial error of orifices uses the laser’s characteristics to finish the measurement and have good measuring results at the same time.

2. System structure and measuring principle

The measuring system is made up as figure 1, mainly composed of laser collimation system, position adjusting device, optical target, area array CCD-image measuring system, data acquisition and processing system made up of image card and computer. Laser collimation system is made up of laser, optical telescopic system and laser electrical source. Position adjusted device is composed of level adjusting device and orientation adjusting device. The orientation adjusting device rivets the position when adjusting the plumb by laser, the level adjusting device is used to observe and adjust plumb during concretely measuring by level degree.

![Figure 1. Structural schematic diagram of measuring system.](image)

Optical Target \[\rightarrow\] Position Adjusting Device \[\rightarrow\] Laser Collimation System \[\rightarrow\] CCD \[\rightarrow\] Data Acquisition and Processing System

The measuring principle of the measuring system is showed as figure 2, the laser, emitted by semiconductor laser which is laid on the focus of the set of lens, becomes parallel reticle beam of light via reticle focus glass and spectrocope, then, emits. At the same time, the CCD is also laid on the focus of the set of lens and receives the reticle image before and after reflection. Parallel reticle beam of light emits to the mercury tin under the pipe casting. It is known from the deadweight and reflectivity of mercury that if the incident ray and catoptric ray go superposition, the measuring instrument is plumb. Here, adjusting the level adjusting device to zero position, then the indicating value’s change of the level adjusting device is also the change of plumb. Because the measure of Flange Place need be measured in plumb placement, the coaxial error just can be measured when it is plumb placement. After adjusting the verticality by laser, lays the transparent circle ring-like optical target underneath the pipe casting, and lights using ordinary diffuse reflection, images to CCD (the imaging place can be adjust) via optical telescopic system, finishes the measure of coaxial error by processing the image of optical target.

![Figure 2. Schematic diagram of measurement C: CCD  L: Laser  I: image card  PC: computer T: optical ringed target  L₁: combinatorial lens  L₂: spectrocope L3: reticle focus glass.](image)
3. Measuring method analyzing and adjusting
The measuring instrument is designed to measure the coaxial error of the four parts of Flange Place, oriented trepan boring, mimic panel and faucet of experiment fast neutron reactor in nuclear power equipment, showed as figure 3. It is requested to finish the measurement of coaxial error of the holes in the four parts in plumb placement (the faucet is rotational).

![Figure 3. Schematic diagram of equipment assemblage.](image)

The laser takes mirror reflection on the surface of mercury, having high precision of plumb by the incident ray and catoptric ray go superposition, the system can counteract the error caused by the
excursion of laser beam. During the practically measuring, we measures at 0 degree and 180 degree and average the data in order to reduce the measuring error. Show as figure 4, if taking the optical target at 0 degree as \((x_1, y_1)\) and the optical target at 180 degree as \((x_2, y_2)\), the final reticle center is \[x = \frac{(x_1 - x_2)}{2}, \quad y = \frac{(y_1 - y_2)}{2}\]. In this way, the optical pathway warp caused by assemblage can be counteracted.

The test results show the measuring way is fitter for the measurement in factory with unstable environment. In assemblage and jointing, the pull in jointing might cause the pipe casting deflection; use the laser’s visibility to take the laser adjusted plumb as plumbing and join symmetrically at the bottom of Flange Place. It is finished assemblage over keeping the reticle in good plumb placement.

### 4. Measuring data

The measuring instrument has passed the verification of Heilongjiang Province Institute of Measurement and Verification (Reports serial number: 12028-05-0, Angle resolving power is: 0.3; displacement resolving power is:0.02mm; respective degree of uncertainty of measurement results are: 0.1; 0.01mm) and has been using in the actual measurement.

After using The Measuring Instrument of Plumb Coaxial Error for Long-distance Orifices to measure with the 6m, have data as table 1. After the measure with 10m, have data as table 2.

| Tube number | X- deviation (mm) | Y- deviation (mm) | Eccentricity (mm) |
|-------------|-------------------|-------------------|------------------|
| 0           | 0.39              | 0.46              | 0.60             |
| 1           | 0.35              | 0.11              | 0.37             |
| 2           | -0.32             | 0.11              | 0.34             |
| 3           | 0.60              | 0.56              | 0.82             |
| 4           | -0.32             | -0.53             | 0.62             |
| 5           | 0.18              | 0.42              | 0.46             |
| 6           | -0.63             | -0.46             | 0.78             |
| 7           | 0.56              | 0.60              | 0.82             |

Table 2. the data of measuring faucets to mimic panel(10m).

| Tube number | X- deviation (mm) | Y- deviation (mm) | Eccentricity (mm) |
|-------------|-------------------|-------------------|------------------|
| 0           | 0.50              | -1.16             | 1.26             |
| 1           | 0.00              | -0.17             | 0.17             |
| 2           | 0.83              | -0.83             | 1.17             |
| 3           | -1.00             | -1.16             | 1.53             |
| 4           | -0.50             | 0.17              | 0.53             |
| 5           | 0.82              | -0.50             | 0.96             |
| 6           | -0.17             | -1.00             | 1.02             |
| 7           | 1.16              | 1.16              | 1.64             |

By analyzing the instrument system and measuring data with 10m, the error affect the measuring system is:

1. Error of aim at reticle: the error is mainly caused by the reflection of mercury and the diffraction caused by laser via the reticle focus glass. While the angle can be distinguished the error is:

\[\delta = L \beta \tan \theta\]

\(L\)—the length of pipe casting is 10m
\(\beta\)—magnification is 0.084
\( \theta \) — angle resolving power is 0.3”
\( \delta_1=0.0012 \text{mm} \)

(2) Error of image processing: this error directly affects the next operation about the target center’s coordinate in the field of vision, in the calculation first using medium filtering and threshold value technology to process, and having the target center’s coordinate by calculating the centroid with floating point numbers. The orientation error is less than 0.1 pixels, as:
\[
\delta_2=0.014 \times 0.1=0.0014(\text{mm})
\]

(3) Offset error caused by focalizing the CCD in the vertical guide track: if there was an \( \alpha \) angle in the vertical when the CCD is moved, the offset error would be
\[
\delta_3 = L \tan \alpha
\]

thereinto: \( \alpha \) — the straightness accuracy of the guide track in vertical (second)
\( L \) — the maximal focal range of CCD (mm)
\( L=66 \text{mm}, \alpha=2” \)
\( \delta_3=6.39954 \times 10^{-4} (\text{mm}) \)

(4) Displacement error of measuring system: see the appraisal report, the error is 0.02mm
\( \delta_4=0.02(\text{mm}) \)

The resultant error from above is
\[
\delta = \sqrt{\delta_1^2 + \delta_2^2 + \delta_3^2 + \delta_4^2} \approx 0.0004 \text{ (mm)}
\]

So it is known that the maximal measuring result with 10m is: 1.6 \( \pm \)0.0004(mm)

5. Conclusion
Seeing from the idiographic data and analyse, the way that combines laser collimation and image processing based CCD is used to measure the plumbing coaxial error for long-distance orifices provides a quick, effective and exact way for precision measurement of manufacture and coaxial error measurement of assemblage with plumb placement of the large or heavy pipe casting equipment. It overcomes the limit of traditional coaxial measuring methods, not only be used for measurement of manufacturing precision about one or several synthesis items, but also be used for measurement of assemble precision. So the way has significant theory meaning and practical use value.

References
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