

# Automatic Verification System for Flatness Error of Large Flat

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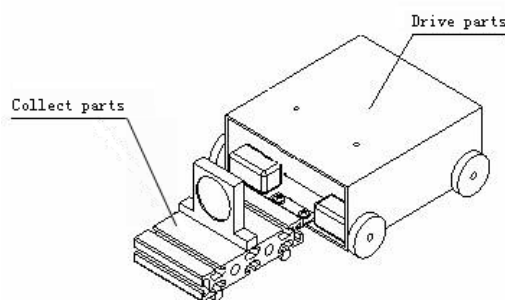
**Abstract.** This paper introduces the detection method of flatness error of flat plate, designs a large-scale flatness error automatic verification system. The structure, working principle and flatness error of least square method are described in detail, the uncertainty is analyzed. The advantages of the system are compared and analyzed by experiments, and it has a good application value.

## 1. Introduction

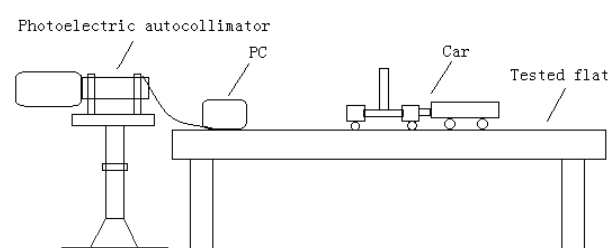
Large flat is used in a wide range of applications such as military, heavy industry and other enterprises. On-site testing methods are usually used for verification due to its large size, weight, and extremely inconvenient to move. The traditional detection method uses bridge plate and electronic level to carry on the segmentation examination, and finally obtains its flatness error through the computation<sup>[1]</sup>. The method is not only inefficient, laborious, but also requires a high degree of skill in the operation and calculation. Sometimes, the result of the test is not reliable and needs to be re-tested. Therefore, it is necessary to find a convenient, accurate and reliable method to replace the manual operation.

## 2. System structure and working principle

### 2.1 system structure



**Figure 1.** Structure of the Intelligent Car



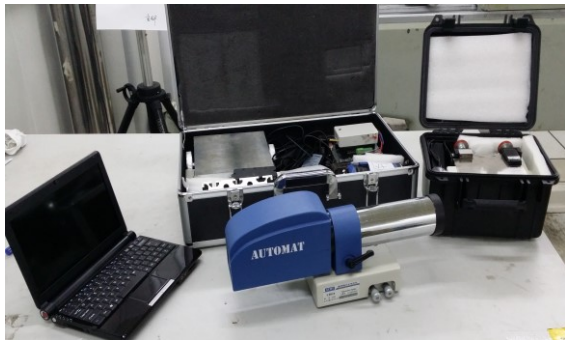
**Figure 2.** System Works

Since auto-collimator is easy to connect with the computer for data transmission, collimator is chosen in the system<sup>4</sup>. An intelligent car is designed to automatically collect measurement data to realize automatic data acquisition in the whole process. The collected data are input into computer and calculated by flatness error software. The whole flatness measurement system consists of the

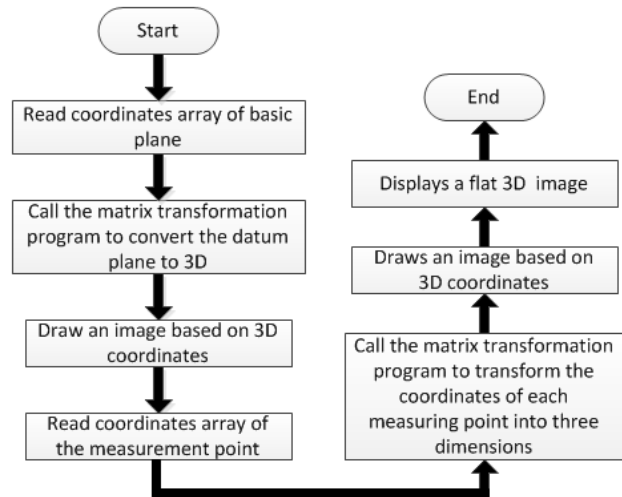
autocollimator, the intelligent car, the flatness error evaluation software and etc. The intelligent car is designed as two parts: drive part and collection part, as shown in Figure 1. The drive section uses two parallel stepping motors on the same side of the collector to control the intelligent trolley. The collecting section is as follows: two aluminum alloy profiles are connected by a long guide rail, two measuring optical axes are arranged at the lower part of the aluminum alloy profile, and the threaded holes are arranged on the long guide rail to adjust the distance between two aluminum profiles to achieve span adjustment.

## 2.2 The system works

The detection process is as follows. First of all, determine the distribution of measurement points according to the size of the flat plate, adjust the span of the aluminum profile and then open the auto-collimator and computer, start the smart car. The drive part of the intelligent car takes the collection part run along the established route. The plane mirror installed on the collection part produce a small inclination with movement. The autocollimator sends the small tilt signal collected into the computer for its storage. After the completion of the whole measurement, the flatness error of the flat plate is calculated by the calculation software, and the measurement is completed. The measurement process is shown in picture 2.



**Figure 3.** Physical Picture



**Figure 4.** Flow chart

## 3. Assessment methods

The least square plane is the plane that points on the measured plane having the smallest distance to it<sup>[2]</sup>. Taking two planes containing the real plane parallel to the least square plane, the distance between the two planes is the flatness error<sup>[3]</sup>.

Suppose there are some measuring points

$$P(X_i, Y, Z_{ij}) \quad (i = 0, 1 \dots k; j = 0, 1 \dots m)$$

The equation of the least squares ideal plane in the three-dimensional coordinate system is

$$\overline{Z_{ij}} = aX_i + bY_j + c \quad (1)$$

The mathematical model of the actual surface of the three-dimensional space can be expressed as:

$$Z_{ij} = aX_i + bY_j + c + f_{ij} \quad (2)$$

According to the basic idea of the least square method

$$\phi(a, b, c) = \sum (z_{ij} - \overline{z_{ij}})^2 = \sum (z_{ij} - aX_i - bY_j - c)^2 \quad (3)$$

Where:  $\phi(a, b, c)$  is the sum of the squared distances of the actual measured value to the ideal plane.

Using the method of extreme value in mathematical analysis to get  $\varphi(a, b, c)$ , respectively, calculate the partial differential of  $a, b, c$ , the equation is:

$$\begin{cases} \frac{\partial \varphi}{\partial a} = -2 \sum (z_{ij} - aX_i - bY_j - c)X_i = 0 \\ \frac{\partial \varphi}{\partial b} = -2 \sum (z_{ij} - aX_i - bY_j - c)Y_j = 0 \\ \frac{\partial \varphi}{\partial c} = -2 \sum (z_{ij} - aX_i - bY_j - c) = 0 \end{cases} \quad (4)$$

Simplifying this equation:

$$\begin{cases} \left( \sum X_i^2 \right) a + \left( \sum X_i Y_j \right) b + \left( \sum X_i \right) c = \sum X_i z_{ij} \\ \left( \sum X_i Y_j \right) a + \left( \sum Y_j^2 \right) b + \left( \sum Y_j \right) c = \sum Y_j z_{ij} \\ \left( \sum X_i \right) a + \left( \sum Y_j \right) b + Nc = \sum z_{ij} \end{cases} \quad (5)$$

The formula 5 is rewritten in the form of a matrix:

$$\begin{pmatrix} \sum X_i z_{ij} \\ \sum Y_j z_{ij} \\ \sum z_{ij} \end{pmatrix} = \begin{pmatrix} \sum X_i^2 & \sum X_i Y_j & \sum X_i \\ \sum X_i Y_j & \sum Y_j^2 & \sum Y_j \\ \sum X_i & \sum Y_j & N \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} \quad (6)$$

It can be seen from equation 6, the least square ideal plane equation can be determined as long as the parameters  $a, b, c$  be gotten. The corresponding coordinate values  $Z_{ij}$  can be gotten after corresponding coordinate of each measuring point is substituted into the plane equation<sup>[4]</sup>. The flatness error is:

$$f = \max(Z_{ij} - \bar{z}_{ij}) - \min(Z_{ij} - \bar{z}_{ij}) \quad (7)$$

#### 4. Evaluation of uncertainty

1 Measurement repeatability in the standard uncertainty  $u_1(a)$ :

The standard deviation is the standard deviation of the experimental results obtained by measuring the straightness of the same cross-section of the same plate with the pitch method and the self-collimator with the same bridge span, and repeating the measurement ten times<sup>[5-6]</sup>.

It can be measured by continuous measurement column and use A-type assessment method for assessment. First of all, determine the section measuring span of 500mm according to the measured section length. The same measurement point takes continuous measurement for 10 times in the same repeatability measurement condition. The intelligent car takes the bridge plate to move in turn.

$$u_1(a) = \sqrt{\frac{\sum_{i=1}^{10} (a_i - \bar{a})^2}{n-1}} = 0.426'' \quad (8)$$

2 Components of estimation error  $u_2(a)$ :

According to the experimental analysis, the mechanical intelligent drive the bridge plate to move. When the span of the bridge is 500mm, the influence on the numerical value is  $0.002\mu\text{m} / \text{m}$ . The input  $\Delta$  can be considered as uniform distribution.

$$u_2(a) = 0.002 / (0.005 \times \sqrt{3}) = 0.2301'' \quad (9)$$

3 Evaluation of the Uncertainty Component of the Effect of Indication Error of Photoelectric Autocollimator  $u_3(a)$ :

From the calibration certificate, photoelectric autocollimator indication error is  $0.3''$ . It can be considered that within  $\pm 0.3''$  is uniform distribution, so:

$$u_3(a) = 0.3 / \sqrt{3} = 0.1732'' \quad (10)$$

**Table 1.** Standard Uncertainty Schedule

Standard Uncertainty Component $u(x_i)$	Source of Uncertainty	Standard Uncertainty Value $u(x_i)('')$	Sensitivity coefficient $c_i = \frac{\partial f}{\partial x_i}$	$ c_i  \times u(x_i)(\mu m)$
$u(a)$	The error associated with the measurement reading	0.6649		
$u_1(a)$	Measurement repeatability	0.4265	$\frac{\sqrt{n_1 + n_2}}{2} L$	$0.6649'' \times \frac{\sqrt{n_1 + n_2}}{2} \times \frac{L}{1000}$
$u_2(a)$	Positioning error	0.2301		
$u_3(a)$	Self - Collimation Indication Error of Photoelectricity	0.1732		

4 Composite Standard Uncertainty  $u(a)$ :

$$u^2(a) = u_1^2(a) + u_2^2(a) + u_3^2(a) = 0.4265^2 + 0.2301^2 + 0.1732^2 = 0.6649'' \quad (11)$$

5 Extended Standard Uncertainty:

$$u_c^2 = c^2(a) \cdot u^2(a)$$

$$u_c = 0.00167 \sqrt{n_1 + n_2} L \mu m$$

Extended Uncertainty: Taking  $k = 2$ , the extended uncertainty  $U$  is:

$$U = 2u_c = 0.0034 \sqrt{n_1 + n_2} L \mu m$$

Indication of measurement uncertainty:

$$U = 0.0034 \sqrt{n_1 + n_2} L \mu m \quad k=2$$

Where:  $L$ - bridge span, mm;  $n_1$ 、 $n_2$ -the measurement of the long side and short side of the measurement section number.

Large plate of (4000 × 1000) mm, take the span of  $L = 250$ mm,  $n_1 = 16$ ,  $n_2 = 4$ , the flatness of the expansion of uncertainty:

$$U = 0.0034 \sqrt{n_1 + n_2} L = 3.8 \mu m \quad k=2$$

## 5. Experiments

Experiments were carried out on a large cast iron plate (4000 × 1000) mm of Shanghai Aircraft Factory. The two methods of plate flatness error automatic test system and manual test were used to carry on the experiment. Measurements: diagonal method, diagonal span: 258mm, long side, short side span: 250mm, diagonal measurement section  $n_0 = 16$ , long side measuring section  $n_1 = 16$ , short side measuring section  $n_2 = 4$ . The flatness error obtained by manual test was 18.6μm. The final result of the automatic detection system was a flatness of 17.9μm. The comparison found that the difference between the two flatness error of only 0.7μm, which has little affection of the level of plate discrimination. Manually test took 2 hours in the factory, 1 hour for manual calculation in the laboratory, and 3 hours in all. The automatic detection system got the results in 2 hours in the factory which saving time about 33 %. The more prominent advantage is that it can be directly re-measurement when in doubt.

## 6. Conclusion

Automatic verification system of planar flatness error can automatically collect the data, the test conclusion can be reached in the factory, and plane flatness convex state can visually seen. It improves the detection efficiency and avoids the introduction of human error in the measurement process, improves the accuracy and reliability. It can play an important role in the detection of large flat panel and has a good practical application value.

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