Straightness Detection Method and Accuracy Analysis of Guide Rail Parts

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Abstract. Guide rail is widely used in various machine tools. It mainly plays the role of guidance and support. The geometric accuracy of the guide rail, especially the straightness accuracy, directly affects the stability of the machine tool and the accuracy of the workpiece. By analyzing the common detection methods, application scope and detection accuracy of straightness of guide rail parts, the application occasions and detection accuracy of each detection method are clarified. It provides a theoretical basis and guidance for testers to detect straightness and deal with errors.

1. Introduction
The main function of guide rail is to support and guide the moving parts to move along the specified route. It is a very important part in the machine. Especially in machine tools, the machining accuracy of machine tools is closely related to the shape accuracy of guide rails [1]. The geometric accuracy of guide rail is very high in precision design, detection and assembly, so the detection of straightness is a very important step.

Generally, the straightness error of guide rail includes straightness error in horizontal plane and straightness error in vertical plane. Straightness error means the deviation degree of the actual shape of the machined part from the ideal straight line, that is, the actual straight line is completely enveloped with the ideal straight line in the detection plane, and the vertical distance between the two ideal straight lines is the straightness error, as shown in Figure 1.

Fig 1. Meaning of straightness

2. Detection method of guide rail straightness
In actual production, the commonly used methods for measuring the straightness of guide rail are micrometer method, level instrument method and straightness instrument method.
2.1 Micrometer method
In order to reduce the value of uncertainty of reading during measurement, we let the bridge slab move on the measured guide rail during detection, and the span \( D \approx (0.1-0.25)L \). Among them, \( L \) is the length of the guide rail and \( D \) is less than 500mm. Figure 2 shows the detection of straightness in the vertical plane. First, we put the working surface of the ruler into a horizontal shape and close to the measured guide rail as much as possible. Then, we place the bridge plate with indicator on the measured guide rail and adjust the position of the ruler to make the readings of the indicator on its two end faces equal.\(^2\) During detection, the bridge slab moves on the full length of the guide rail, and the full length is divided into several intervals (the smaller the interval, the more accurate the measurement is). The indicator reads and records when it passes through each interval. Finally, the maximum difference between the readings of the indicator is taken as the straightness error value within the whole length of the guide rail.

Fig 2. Detection in vertical plane

The straightness error of guide rail assembly is generally completed by inspection rod and dial indicator. Firstly, the inspection rod is clamped between the spindle center and the tailstock center, the indicator is clamped on the gauge base, and the gauge base moves along the guide rail direction to ensure that the measuring head of the dial gauge is in contact with the side bus of the inspection rod. The first step is to adjust the position, adjust the transverse position of the tailstock through the reading of the indicator to ensure that the readings of the indicator at both ends of the inspection rod are the same. The second step is to implement detection. We continuously detect the side bus of the inspection rod and observe the dial indicator reading. The difference between the maximum value and the minimum value is the straightness error of the guide rail in the horizontal plane.

2.2 Check the straightness with a level
Level is the most commonly used instrument to detect the straightness error of guide rail. It is simple to operate and has high measurement accuracy. It is generally used for straightness detection in vertical plane. In actual production, the most widely used is the frame level.

The frame level mainly includes a frame and a level. The level is an arc sealed glass tube with scale, which is filled with alcohol or ether and has a certain length of bubbles. For a level with an accuracy of 0.02/1000, when the bubble moves one grid, the angle change of the level is 4 arcmin, that is, the height difference at both ends of the 1000mm length is 0.02mm. As shown in Fig 4.

Fig 4. Measuring principle of level
During the measurement, we put the measured guide rail on the adjustable sizing block and the level gauge on one end of the guide rail. First adjust the guide rail to the horizontal position, that is, the bubble of the level gauge is located in the middle of the glass tube. We move the level in the direction of the guide rail to carry out uniform sectional inspection. Each time we move the level, we should ensure that the head and tail are connected, and record the readings of each section. We should avoid interval or position overlap. This method is called pitch method, as shown in Figure 5.

![Fig 5. Check the straightness of the guide rail with a level](image)

The final recorded data shall be the relative height between the measuring point and the starting point of each section. For example, when testing from left to right, the leftmost reading is 0, and the reading of the level is relative to the left end point. In the next measurement, the reading is relative to the second point. The reading values obtained in turn are the readings of the latter point relative to the previous point. We need to use cumulative addition for data processing to obtain the relative height value of each node relative to the starting point before we can evaluate the straightness error.

### 2.3 Measure the straightness of the guide rail with a straighter

The optical flatness instrument is composed of a flat instrument body and a reflector. The light source emits light beams, passing through the crosshair reticles, and passing through prisms, flat mirrors and objective lenses to parallel beams to shoot onto the reflector. The light beam is reflected by the mirror, and then forms a cross image on the eyepiece dividing plate through the objective lens, flat lens and prism. When adjusting, we can adjust the reference line in the eyepiece with the cross image by adjusting the micro knob and display the deflection angle of the readout mirror according to the scale on the knob, as shown in Fig. 6.

![Fig 6. Working principle of optical flatness instrument](image)

The straightness meter can measure the straightness error in the horizontal and vertical planes. If the straightness in the horizontal plane is measured, rotate the eyepiece by 90°.

### 3. Evaluation of straightness error

The common method for evaluating geometric error is the minimum condition method, that is, the measured elements are completely enveloped with the inclusion area with the minimum width or diameter, which is the size of straightness error, as shown in Figure 7.
We process the data according to the measured reading value to obtain the size of straightness error. The common methods of data processing mainly include drawing method and calculation method.

### 3.1 Drawing method

According to the reading value of the actually extracted constituent elements measured by the micrometer method, level detection method or straighter method described above, we can find the minimum area by drawing method, and then measure to obtain the size of straightness error. Generally, we take the serial number \( n \) of the measuring point in the length direction of the measured element as the abscissa, and the ordinate as the reading difference \( m \) of each point relative to the starting point. The prime line on the measured actual guide rail surface can be approximately obtained by tracing points. For example, we use a level to measure the straightness error of the machine tool guide rail, and successively measure the readings of each point as \((\mu m) : 0, -1, +3, +1, +1, -2, -4, +2\), we can accumulate the reading values of each point relative to the starting point, as shown in Table 1.

| Measuring point serial number \( n \) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|-------------------------------------|---|---|---|---|---|---|---|---|
| Read value                          | 0 | -1| +3| +1| +1| -2| -4| +2|
| Cumulative value                    | 0 | -1| +2| +3| +4| +2| -2| 0 |

As shown in Figure 8, we make the approximate curve of the actual elements according to the measured values, find out the minimum area, and measure the actual straightness error value, which is about 5.6\( \mu m \).

### 3.2 Calculation method

First, we calculate the average of the readings, then subtract the average from the original readings, and then accumulate the difference one by one. Finally, we take the maximum \( a \) of these values to calculate the straightness error.
4. Detection accuracy analysis

The main factors affecting the straightness detection accuracy of guide rail are the uncertainty of instrument and the reading error during detection. The uncertainty of the instrument is the inherent error of the detection instrument itself. The detection error mainly includes reading value, detection method error and data analysis method error\(^6\). In addition, it is also affected by factors such as testing environment and testing personnel.

4.1 detection accuracy of micrometer method

The detection instruments used in micrometer method are mainly indicator and flat plate. The detection error is
\[
\delta = \sqrt{\delta_1^2 + \delta_2^2},
\]
and the instrument accuracy error is \(\delta_1\) can be expressed as
\[
\delta_1 = \sqrt{\delta_{\text{indicator table}}^2 + \delta_{\text{flat ruler}}^2 + \delta_{\text{slider}}^2}.
\]
If the length of the guide rail is 1500mm, use a class 00, 1000mm ruler and a dial indicator with a division value of 0.002mm to detect. The surface accuracy of the guide rail and slider is high, and the error caused by it is less than 5.6\(\mu m\).

\[
\delta_2 = \delta_{\text{indicator table}} + \delta_{\text{flat ruler}} + \delta_{\text{slider}} = \sqrt{2^2 + 3^2 + 0.56^2} = 3.65\mu m
\]

\(\delta_2\) depends on environmental error and estimation error. The environmental error is ignored, and the estimated reading error is about 1\(\mu m\). Therefore, the measurement error of micrometer method is about 3.77\(\mu m\). And the larger the measurement length, the faster the detection error increases.

4.2 detection accuracy of straightness detected by level

The main instruments used in this method are level and slab bridge. The accuracy of the level commonly used in enterprise production is 0.02mm/1000mm. If the span of each section is 250mm, the measurement error of the level is about 0.005mm\(^7\). The fitting error between guide rail and slab bridge bottom is less than 1\(\mu m\). Then the error of the testing instrument is
\[
\delta_i = \sqrt{\delta_{\text{level}}^2 + \delta_{\text{slab bridge}}^2} = \sqrt{2^2 + 1^2} = 5.1\mu m
\]

4.3 use the straightness tester to detect the detection accuracy of straightness

The main instruments used in this method to detect straightness are straightness instrument and reference plate, and the instrument accuracy error is very low \(\delta_i\). It is composed of measurement accuracy error of straightness instrument and substrate bonding accuracy error. If the minimum reading of the collimator drum is 1 "and the length of the base plate is 250mm, the detection accuracy can be found to be 0.0012mm by looking up the table. The substrate bonding accuracy error is less than 1\(\mu m\). So \(\delta_i\) is about 1.56\(\mu m\).

The reading error of the straighter is mainly affected by the estimated reading error. The estimated reading error is 0.0006mm, so the total error is 1.67\(\mu m\).

5. Conclusion

Through analysis and comparison, the measurement error of micrometer method is about 3.77 under the same external conditions\(\mu m\). It should be used to detect guide rail parts with small length. The detection error of straightness detected by level is about 5.1\(\mu m\). The accuracy is low and can only be used to measure the straightness error in the vertical plane. The detection error of straightness detected by straightness instrument is about 1.67\(\mu m\). It is generally used to detect the straightness of long guide rail parts with high precision.

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