# Parallelism Measurement Methods

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At present, the parallelism error was evaluated by contact probe, laser interferometer, and autocollimator, etc. Moreover, it can also be divided into contact method and non-contact method based on the measurement principle.

parallelism Contact method Non-contact method

## 1. Contact method

The contact method was carried out mainly by dial indicators or contact probes. The parallelism was measured by contacting the surface directly.

### 1.1 Evaluation of parallelism by thickness difference

In this method, a series of thickness values of the workpiece are measured in the sampling area. The difference between the maximum thickness and the minimum thickness of the sampling area is considered as the parallelism error of the workpiece [1][2]. Thus, the parallelism is based on the thickness of the workpiece, in which the accuracy is related to the sensor used in the measurement. In the measurement, two coaxial contact probes are selected as measuring instruments, and calibrated gauge blocks are used as the standard. The two contact probes first contact the two surfaces of the calibrated gauge block respectively, which make the sensor's initial value is set to zero. Then, the two surfaces of the workpiece are measured simultaneously. The displacement of the two probes indicates the thickness difference between the test block and the reference block at the measurement point. The workpiece can also be placed on a reference plate, and measure the other surface with a dial indicator. The thickness difference indicates the parallelism error between the two surfaces of the workpiece.

### 1.2 Calculation of parallelism by measurement algorithm

In this method, the contact probes are used to scan the contour surface, the parallelism error of the measurement contour is obtained by processing the measurement data through an algorithm. Establish a coordinate system between two measurement contours, and move the scanning table carrying contact probes (displacement sensor) between the two measurement contours in the direction of the specified coordinate system [3]. Building output function of the displacement sensor, and calculates the parallelism error [4][5][6]. Another way, high-precision reconstruction of measurement contours by double differentiation and double integration of measurement data, and use the reconstruction results to calculate the relative positions of the two measurement contours to evaluate their parallelism [7].

The contact method is suitable for measuring the parallelism of small and medium-sized non-transparent workpieces, machine tool guideway or carriages and the spindle of the work head. It's accuracy is related to the displacement sensor and data processing methods. The contact method can ensure stability in complex measurement environments [8], and comprehensively consider the impact of the initial state of the workpiece surface and the equipment movement error. The measurement accuracy can reach sub-μm level.

# 2. Non-contact method

The non-contact method mainly uses interferometer, autocollimator or design a special light path to measure the parallelism error of the workpiece. The measuring device can perform parallelism measurement without touching the workpiece through the conversion of optical signals (movement of interference fringes, changes in light phase differences, movement of light focus points, etc).

## 2.1 Interferometer-assisted optical method.

An interferometer is a geometric measurement instrument that can measure multiple parameters such as linear positioning, straightness, perpendicularity, parallelism, and angle. For the measurement of transparent workpieces. The basic principle of is that the laser light source enters the rhombic beam splitting prism to form a parallel beam, which irradiates the two surfaces of the workpiece, the two surfaces with parallelism errors change the optical path and produce interference phenomenon. The parallelism of the workpiece is measured by analyzing this phenomenon [9][10][11][12][13][14].

For the measurement of non-transparent workpieces. The basic principle is to place the workpiece between the right-angle prism and the reference plane. The light source is incident on the two surfaces of the workpiece through the reference plane and the right-angle prism. The light reflected from the two surfaces of the workpiece interferes with the light reflected from the reference plane. By analyzing the two interference patterns, the parallelism of the workpiece is measured [15][16][17][18]. Laser interferometer and profilometer can also be used in combination to generate 3D images to measure workpiece parallelism [19][20] .

## 2.2 Autocollimator-assisted optical method

Autocollimator is a kind of measuring instrument that uses the principle of autocollimation to convert angle measurement to linear measurement. It is widely used in the measurement of angle, parallelism and flatness. In this method, the light passes through the objective lens to form parallel light. The side of the plate under test that is perpendicular to the optical axis is used as the incident front surface, and the parallel beam is incident perpendicularly, the two parallel beams of light are reflected from the front and back surfaces of the plate, if there is a parallelism error between the two surfaces of the plate, there will be an angle between the two parallel beams of light reflected. The focus formed on the focal plane after the reflected light passes through the objective lens will move, and the amount of focus movement is the parallelism of the two surfaces of the workpiece [21][22][23][24].

### 2.3 Diffraction and ultrasonic echo methods

The laser light source passes through two orthogonal diffraction gratings to generate diffraction straight lines on the workpiece as a reference lines. The reference line on the workpiece surface is captured by the camera, and the parallelism deviation of the reference line on the image indicates the parallelism of the workpiece. This method can measure the parallelism of large targets[25][26]; The ultrasonic reflection method uses the longitudinal wave generated by the transducer is perpendicularly incident on the first surface of the workpiece. Due to the parallelism error between the second surface and the first surface, the reflected wave will have a certain deviation from the normal direction. Then, the parallelism of the workpiece was measured by analyzing this phenomenon[27].

The non-contact method is suitable for measuring parallelism of transparent workpieces, small non-transparent flat workpieces, and machine tool guideway. The measurement accuracy is high and the stability is good. However, this method requires control the measurement environment strictly. The measurement accuracy can reach nm level.

## 3. Comparison of Different Parallelism Measurement Methods

| Methods | | Object | Measurement environment | Stability | Precision |
|---|---|---|---|---|---|
| Contact method | Evaluation of workpiece parallelism by thickness difference (measurement by dial indicator) | plate workpiece | Can adapt to complex measurement environments | Worse | mm |
| | Evaluation of workpiece parallelism by thickness difference (contact probe measurement) | | Can adapt to complex measurement environments | better | sub-μm |
| | Calculation of parallelism by measurement algorithm. | Small and medium-sized non-transparent workpieces or machine tool guideway | Can adapt to complex measurement environments | better | sub-μm |
| Non-contact method | Use of parallelism measuring equipment such as interferometers and autocollimators | Transparent workpiece, small non-transparent flat workpiece or machine tool guideway | High requirements on the measurement environment | good | nm |

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