TEST METHOD FOR SINGLE INTERIOR RIGHT ANGLE IN A CORNER CUBE PRISM

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KEY WORDS corner cube prism; right angle measurement; autocollimation

ABSTRACT A new test method for single interior right angle in a corner cube prism is presented. Some key points and parameters are analyzed and derived. The advantage of this method is concluded by comparing with some current conventional methods.

1 Introduction

The corner cube prism or retroreflector is extensively used in place of the movable mirror in an interferometer, or as a cooperative target in range finder. It has three surfaces, which are perpendicular to each other and called the right angular surfaces. An inclined isosceles triangular surface is shown in Fig. 1. Ideally, it will make the reflected ray, which is incident to the inclined surface and enters the prism, totally internally reflected at each right angular surface and then exit through the original inclined surface, and parallel to the incident ray.

The key point in the manufacture of this kind of prism is how to control the error of every right angle between two perpendicular surfaces, which in turn is how to measure them accurately.

One of the current methods to measure the error of right angle is to compare it with a high precision standard block with right angle, which is very expensive and is dependent on the accuracy of the testing goniometer. This way can be called exterior angle comparison.

Another way is to use an autocollimator as shown in Fig. 2. A pinhole or cross-hair on the reticle is projected to infinity by the objective of the autocollimator. If the corner prism is placed in front of the autocollimator with the isosceles triangular surface toward the collimator. After refraction and totally internal reflection three times and refraction again, six images of the reticle will appear in the focal plane of the autocollimator, if there are errors in the right angles of the prism. The separations among the 6 images imply the magnitude of the errors. This is the autocollimator test of three interior right angles and it belongs to a comprehensive test method, however it is difficult to identify one error in the three, especially when cross-hair is applied.

In this paper a single interior right angle test method is presented, which can be used in the process of manufacture.

2 Testing principle

The test apparatus is shown in Fig. 3. The monoch-
romatically illuminated pinhole as an object point is projected to infinity by the objective of the autocollimator and becomes a collimated beam. The beam strikes with inclination to the isosceles triangular surface \( \triangle ABC \) of the corner prism. When the prism is orientated properly, the refracted beam in the prism will hit the edge \( AO \) perpendicularly and parallel to the bottom surface \( \triangle BOC \). Then the beam will be totally internally reflected at \( \triangle AOB \) and \( \triangle AOC \), or \( \triangle AOC \) and \( \triangle AOB \), respectively, while separating to two beams. Obviously, in this case the edge \( AO \) is the intersection line of surfaces \( \triangle AOB \) and \( \triangle AOC \), and plays a role of roof.

After refracted back into the air, these two beams will be imaged at the focal plane of the autocollimator and should be one point when the right angle (or the roof) between \( \triangle AOB \) and \( \triangle AOC \) is exactly correct, or two points with some separation when the right angle has error.

If the illuminated light is white, these images will, instead of point, be colored lines from red at upside to blue at downside because of the dispersion of the prism. The separation between two lines corresponds to the magnitude of error of roof angle.

In a word, the properly inclined and orientated corner prism makes the autocollimator image separate or coincide in horizontal direction and disperse in vertical direction.

### 3 Some derivations

1) The refracted ray into the prism should be perpendicular to the edge of \( AO \), so the incident angle is not arbitrary. According to the refraction law

\[
sin i = n \sin i'
\]

where \( n \) is the refractive index of the prism material. From geometry we have

\[
\theta = \arccos(1/\sqrt{3})
\]

and

\[
i' = 90^\circ - \theta
\]

If \( n_D = 1.5163 \), then the incident angle should be

\[
i = 60^\circ.10
\]

2) Assume that the roof angle is \( 90^\circ + \delta \) (\( \delta \) is very small), and the collimated beam from the au-
Test Method for Single Interior Right Angle in a Corner Cube Prism

A test collimator is purely monochromatic and refracted into the prism. According to the reflection law, the twice reflected beam in the roof surfaces will have a small angle $2\theta$ with respect to the incident beam. Therefore the two reflected beams, which are formed by two different reflection sequences, i.e., from $\triangle AOB$ to $\triangle AOC$ and from $\triangle AOC$ to $\triangle AOB$, will have an angle of $4\delta$. If two rays forming angle of $4\delta$ are retro-incident to $\triangle ABC$ at nearly the same incident angle $i'$ and strike $\triangle ABC$ at one point but existing in two incident planes angling $4\delta/sin i'$, and refracted from the glass to the air. The two emerging rays will have an angle of $4\delta'$ and in their original incident planes respectively, but at nearly the same refractive angle $i$. Because the angle between two incident planes are exactly equal to the angle between two emerging planes, we have

$$4\delta/sin i' = 4\delta'/sin i$$

and

$$4\delta' = 4n\delta$$

These two retroreflected beams will be imaged in the focal plane of the objective of autocollimator with separation

$$s = 4\delta'f'$$

where $f'$ is the focal length of the objective. We write

$$\delta = s/4nf'$$

When $s$ is measured, and $n, f'$ as two constants, are known, it is easy to calculate the roof error of $\delta$. Here $\delta$ is very small (e.g., $\delta = 1'$), $n \approx 1.5$, even if $f'$ is rather large, e.g., 2 m, $s$ is in the order of $60 \mu m$.

From Eq. (8), the relative error is

$$\frac{\Delta \delta}{\delta} = \left[ \left( \frac{\Delta s}{s} \right)^2 + \left( \frac{\Delta n}{n} \right)^2 + \left( \frac{\Delta f'}{f'} \right)^2 \right]^{1/2}$$

So accurate measurement is the most important.

By means of CCD and image processing technique, the measurement of $s$ could be easily performed and calculated by computer automatically.

3) The sign of $\delta$ may be positive or negative, however, the appearance of images in the focal plane is the same no matter what the sign is. Therefore the problem of sign has to be solved so that this method becomes practical.

Fig. 4 depicts the principle of sign recognition, where two cases $(\delta > 0$ or $\delta < 0$) are shown. If the observation plane is out of the focal plane, the appearances are different despite they are the same in the focal plane when the errors in two cases are equal but the signs are opposite. By comparing the result out of the focal plane with one in the focal plane, the sign can, out of doubt, be recognized.

4 Conclusion

This method adopts only the autocollimator, which is one of the most conventional instruments in workshop or lab. Substantially, it is the conversion from angular quality to linear one. As we have seen, the error $\delta$ is $4n$ times magnified by interior reflection and refraction of the prism, and converted to linear separation by a large multiple factor of $f'$ to make the test easy. It does not need using 90° standard gauge of high precision and high cost, and suits especially to the application in the production process. The most remarkable advantage of this method is testing single roof error precisely, definitely and exclusively without any confusion due to other two roof errors.

Reference

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