Research on the Methods to Compensate the Systematic Error at Optical Autoreflection Angular Measurements

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Abstract. Autoreflection measurement devices have very wide applications in produce of instrument, machine and metrical technology. They are used for ensuring status of details, units and planes, and for the control of the displacement of revolving converters, in the national standard planar angle. The main systematic error in autoreflection measurement methods is an error caused by vignetting. The analytic research of function describing this error was made. The experiment was made to ensure the analytical results. The parameters of experimental device were the following. The distance from the mirror 8 m, aperture of the receiving objective 65 mm, aperture of the mirror 78 mm, diameter of the radiating surface of the LED 2mm.

1. Structure and the main principles of optical autoreflection measurement device

The experimental device is an angular measurement system with a point mark, placed in a finite distance. The structural scheme is presented on figure 1.

Figure 1. 1 – light emission diode (LED), 2 – flat mirror, 3 – objective, 4 – charged couple device (CCD).

Device operation principle is described below. Flux of radiance is sent by the LED 1 to the flat mirror 2. Flux of radiance is reflected back and focused by objective 3 on the CCD 4, placed in plane, coupled with the plane of the LED’s image, formed by mirror. When the mirror is rotated round the collimation axes (perpendicular to the optical axis) displacement of the LED image in the CCD plane is proportional to the mirror rotation angle. The information about sign and value of mirror rotation round the collimation axes can be obtained by measuring the coordinates of the LED’s image in the CCD plane.
Device optical scheme is presented on figure 2

2. Analysis of optical autorefection measurements errors
The error under consideration appeared because of the different vignetting of various beams, forming the LED image in the CCD plane. The vignetting elements are the mirror aperture and the objective aperture. Vignetting error doesn't appear when all LED beams passed through objective symmetrically to the optical axis, for example in zero mirror rotate angle case. Corresponding to the mirror rotate angle some LED beams offset exceeds the bounds of objective frame. This event gives rise to the energy dissymmetry of the LED image in the CCD plane (figure 3, 4). The result is that the center of energy distribution of the image and geometrical center of the image have different coordinates.

The special feature of a CCD, as an analyzer, is that it registers the coordinates of the center of energy distribution in the image, and as it is mentioned above the coordinates of the center of energy distribution and coordinates of geometrical center of the image are not the same when the vignetting takes place.

The difference between energetic and geometrical center is called measurement error caused by the vignetting.

The relative error of the angular measurement $\Theta$ caused by the vignetting in the small measurement range (under 10 arc minute) with the quadrant LED is determined by the expression:

$$V_\sigma = 0.65 \frac{4* l_D * \beta_k}{\pi - 4* l_D * \beta_k}$$

\[ \beta_k \] – the angle of the beam derivation, \( l_D = L/D \), \( L \) – the distance from the mirror, \( D \) – the distance from the mirror to the objective.
diameter of the objective aperture.

![Figure 4. The energy distribution in the LED image.](image)

The function $V_\alpha$ is illustrated by the figure 5, where the same designations are used.

![Figure 5. The relative error caused by the vignetting.](image)

As the graph claims the error is rather big even in enough short measurement range and small distance (about 1 m) and big aperture (100 mm). Its value comes to several percents, which is not allowed in precise measurements.

So the research of algorithmic compensation of this error is very important because it can lead to the increase of measurement range.

3. Physical experiments

The method of physical experiment was the following. The mirror was placed on a holder with an angular movement in horizontal plane. The mirror rotation around one of the collimation axes was made by rotation of a movement drum. The value of the rotation was the system input parameter.

During the experiment a measurement data was obtained in the following conditions:

- distance from the mirror 8 m
- aperture of the objective 65 mm
- aperture of the mirror 78 mm
- diameter of the radiating surface of the LED 2 mm

In the course of the experiment the range of mirror rotation and the LED feeding current was varied.

4. Analytical circumscription of the systematic error function

The analytical circumscription of systematic error function was made in the following way. At first the
dependence between the vignetting of light beams and the angle of mirror rotation was found. As the beam form is similar to a pyramid (it is caused by the rectangular shape of the mirror), the area of intersection between the beam profile and the objective frame is equal to the area of a segment of a circle, which is a result of this intersection (it is illustrated by figure 6).

Figure 6. The geometrical correlation between the beam and the aperture. \( f \) – index of the segment.

The area of intersection between the beam and aperture was separated to the slices. Each slice width is \( \delta D \). Starting from the geometrical correlations in the device scheme the next expression was obtained:

\[
S_{1i} = \frac{r^2}{2} \left[ 2 \cdot \arccos \left( i \cdot \frac{\delta D}{r} - 1 \right) - \sin \left( 2 \cdot \arccos \left( i \cdot \frac{\delta D}{r} - 1 \right) \right) \right]
\]

where \( r \) – the radius of aperture, \( \delta D \) – the width of the i’th slice in millimeters.

The result of such mathematic exercise is an array \( S_1 \) expressing the value of the intersection area in dependence on the angle of mirror rotation in implicit form.

This array defines the energy distribution in the LED image. The array \( X_e \) is made from the array \( S_1 \) considering the LED diameter.

The location of the geometrical center of the LED image in dependence on the mirror rotation is known and it is placed into an array \( X_{ge} \). The difference between the elements of these arrays, \( X_{ge} - X_e \) is the theoretical value of the error, caused by the vignetting.

5. Comparison of experimental and theoretical results
The results obtained experimentally were worked up to make them appropriate to compare with the theoretical function. The both arrays are presented by graphs on figure 7.
This graph shows that the results have much in common. This circumstance allows to hope to compensate the systematic error caused by the vignetting.

6. **Compensation of the systematic error caused by the vignetting**

As a result of described work the analytic function was obtained. This function gives the values of the systematic error caused by the vignetting in full measurement range.

A device including a system compensation of the systematic error caused by the vignetting will have a wider measurement range with given error. The error in the centre of the measurement range will decrease a lot.

**References**

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