Optic-electronic autocollimator for inspection deformations of the axle at the millimeter wave range radiotelescope

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Abstract

Researches in the millimetre wave range require the high accuracy for position of the mirror components of the radiotelescope. A mirror weight is the cause of the three-dimension angular deformation of the elevation axle and azimuth axle relatively bearings. For the measuring roll, pitch and yaw angular deformations of the axles the autocollimator with new type of the reflector are used. Reflector as the composition of the anamorphic prism and tetrahedral reflector is described. New methods for roll, pitch, yaw angles measuring are discussed. Equations for the static characteristic of the measuring system are shown.

Keywords: Autocollimator, pitch, yaw and roll, cube-corner retroreflector, anamorphic wedge, radiotelescope

1. Introduction

Nowadays new radio astronomy instruments are designed for researches in the millimeter wave range. For example, Sardinia SRP radiotelescope (Italy) with 64 meters diameter mirror, the NRAO RT with 45 m mirror (Japan) and RT-70 Suffa radiotelescope with 70 meters diameter mirror (Russia).

There is a necessity to realize the accuracy angle position between construction elements of radiotelescope. The research in the millimeter wave range requires the few (no more 2 arc. seconds) deviation of the parabolic mirror axis relative to the theoretic one. The deformation of radio telescope elements at the time of installation and at the research work period makes some problems.

The construction weight and the temperature influence are the reason of the radiotelescope component deformations. For example, angular deformations of axles for mirror elevation or azimuth rotation are value as 6-30 arc minutes [1].

A weight of the parabolic mirror causes the three dimension deformation elevation axle relative to the theoretic direction. The three dimension deformation is roll, yaw and pitch angles deviation the axis line of the elevation axle (Fig. 1). As result the direction of a parabolic mirror axis after setting in elevation and in azimuth is not equal to the accuracy angular values, which are determined by the electric turn drive system at the axle bearings. This deformation of axles must be measured and corrected. Therefore it is necessary to realize the special system for measure the angular deformation of the elevation axle and mirror support.

Optic-electronic autocollimators, which permit the realization of quick and high-precision measurements, automation of the process of taking readings, and an increase in the reliability of the information obtained, are widely used to accomplish this task.
2. Analysis of metrology problems

The system for measuring deformations must be positioned within tube of elevation axle. According of this requirement the autocollimator is installed on the bearing of the elevation axle as the rigid base (Fig. 1). The reflector is set in the point \( O' \) of maximum deformations.

The measurements of three-dimension deformations of elevation axle calls for the realization of high-precision measurements with an error not more 2 arc seconds \((10^{-5} \text{ radian})\). The measurement range is 6 arc minutes for pitch and yaw angles and several degree for roll angle (of the order of \(10^{-2} – 10^{-1} \text{ radian}\)). The work distance is determined by the half length of axle, which value for radiotelescope RT-70 Suffa is the 10 meters \( [2] \).

The main metrology problem is to measure the roll angle \( \Theta_3 \). The traditional reflector element for autocollimation method is a plane mirror. The plane mirror is effective for measure only two angular coordinates – pitch \( \Theta_1 \) and yaw \( \Theta_2 \). Using the traditional autocollimator it is impossible to measure the roll angle \( \Theta_3 \) as third angular coordinate.

The tetrahedron reflector with non-plane side is effective for measuring roll \( \Theta_3 \), pitch \( \Theta_1 \) and yaw \( \Theta_2 \). The tetrahedron reflector generates the wide reflected beam and autocollimation method is realised if the aperture of the optic path is equal to 100 mm and more. But it is necessary to use the narrow reflected beam, because the inside diameter of the elevation axle tube is about 50 mm and less.

As the result it is necessary to synthesize the reflector element for autocollimation measurements with three facilities.

1. The autocollimator with this reflector can measure all three angular coordinates – pitch \( \Theta_1 \), yaw \( \Theta_2 \) and roll \( \Theta_3 \);
2. The reflected beam is collimation and narrow.

It has been proposed to realize the reflector, which contains two parts which are situated on the same axis. First part is the telescopic anamorphic prism and the second part is cube-corner retroreflector (Fig. 2).

![Fig. 1. Autocollimator and reflector for measure roll, pitch and yaw angle deformations.](image)

The radiating channel of autocollimator includes the laser diode 3 as the source of radiation and aperture-mark 2, which is placed in the focal plane of objective 1 \([3]\). The radiation channel generates the collimation optical beam and directs it on the reflector (Fig. 2). The reflector concludes the anamorphic wedge system 4 and ordinary cube-corner retroreflector 5. The anamorphic wedge system 4 is set on the half part of the aperture of the cube-corner retroreflector 5. The incident optic beam is divided into two parts. The first part passes across anamorphic system and cube-corner retroreflector (line arrows in Fig. 2). The second part is reflected by the front plane of the cube-corner retroreflector 5 as the mirror...
(dash arrows in Fig. 2). These reflected beams are received by the autocollimator. The receiving channel of autocollimator includes the objective 1, semi-reflecting splitter 6 and the photo-receiving CMOS matrix 5, which is placed in the focal plane of objective 1. The reflected beams form on the photo-receiving matrix 7 the two images of the aperture-mark 2. The video-frame from matrix 7 is calculated by the digital microprocessor 8 (Fig. 2).

When the reflector rotates on angles $\Theta_1$, $\Theta_2$ and $\Theta_3$, the reflected beams are deviated from the original direction. As result the first image varies the shape and the second image shifts on the matrix photoreceiver. The microprocessor 8 calculates the video-frames from the matrix photoreceiver and determines the parameters of the images. Three angular coordinates $\Theta_1$, $\Theta_2$, and $\Theta_3$ of the reflector 4 are determined as a result of the processing image parameters.

3. Algorithm for measure the roll, pitch and yaw angles

The first part of proposed reflector is the telescopic wedge anamorphic system. Anamorphic optic elements change the height or width of an incident beam along one dimension by a specified amount [4]. The anamorphic wedge expands or compressions the incident collimation beam in meridian plane. As result the scale of the formed image is changed (increase or decrease) along one of the axis. Let the aperture-mark in radiating channel of autocollimator is the triangle shape with height $a$ and angle coefficients $k$ for contour lines (Fig. 3, image 1, thin lines):

$$k = \tan(\alpha).$$

The anamorphic prism transforms the beam with scale $K$ and forms the image on the photoreceiver matrix as the rhomb with diagonal $aK$ (Fig. 3, image 2, bold lines).

If the anamorphic wedge system is rotated relatively axis of incident beam on roll angle $\Theta_3$, the dimension of anamorphic transformation rotates too. As result the shape of the image is changed (Fig. 3, image 3 for roll $\Theta_3 = 20^\circ$). The difference $\Delta k$ between coefficients $k_1,k_2$ for contour lines of the transformed mark can be used as the parameter of the image shape:
In equation (2) parameter $A$ is anamorphic magnification. For alone anamorphic wedge magnification $A$ is equivalent scale $K$ of transformation. Parameters $s$ and $cs$ are ancillary functions:

$$s = \sin(2 \cdot \Theta_3), \quad cs = \frac{A + 1}{A - 1} - \cos(2 \cdot \Theta_3)$$

The microprocessor calculates the video-frames from the matrix photoreceiver and determines the parameter $\Delta k$ of the image shape. The measuring roll $\Theta_3$ is determined as the solution of the equation (2).

The angle deviations of beam which is reflected by the plane part of the cube-corner aperture results in the shifts of the second image on the matrix photoreceiver. The microprocessor calculates the video-frames from the matrix photoreceiver and determines the value of the image shifts. The angular coordinates pitch $\Theta_1$, and yaw $\Theta_2$ of the reflector are determined as a result of measuring this shifts.

4. Conclusion

The reflector as the assemblage of the telescopic anamorphic wedge system and ordinary cube-corner reflector has advantage as the inspection element for autocollimators. The autocollimator with this reflector measures the three-axis angular deformations and the work distance and the range of measurement increases. The researched autocollimator is effective for measure angular deformations of large constructions, for example, fully rotate able radiotelescopes or railways bridges [5].

To verify the theoretical results, an autocollimation goniometer sensor was created. The experimentally determined characteristics: work distance is 8 meters, range of measurement for pitch $\Theta_1$ and yaw $\Theta_2$ angles is 10 arc minutes, range for roll angle $\Theta_3$ is 3 arc degrees. The error of measuring angle coordinates pitch $\Theta_1$, yaw $\Theta_2$ is 3 arc second, error of measuring roll angle $\Theta_3$ is 10 arc second.

The experimental researches of the autocollimation experimental setup have confirmed the correctness of theoretical results.

5. Acknowledgments

This work was financially supported by Government of Russian Federation, Grant 074-U01.

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