Optic-electronic systems for measuring angle deformations of a fully rotateable radiotelescope

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Abstract. The construction of new large radio telescope RT-70 Suffa requires controlling the element angular deformation. Following issues dealing with this problem are described in this article: 1) the possibility of the design of deformation measurement system based on autoreflection scheme, 2) the new vignetting error compensation method. The great attention during the research was paid to the experimental approval of the theoretical results. The model of the described system had the following characteristics: infrared emission diode AL107B by power 15 mWt as sources of radiation; the focal length of receiver objective by the focal length 500 mm as aperture of receiver videocamera, the CMOS matrix receiver by type OV05610 Color CMOS QSXGA with 2592*1944 pixels and one pixel size (2.8*2.8) μm² produced OmniVision as image analyzer. The experimental error measurement was 1.5 arc seconds at the angular range 20 arc minutes, that allows measure the angle deformation of radiotelescope with the mirror diameter 70 m.

Keywords: autocollimator, vignetting, CMOS matrix photo-receiver, measure the angle deformation, radiotelescope

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1. Introduction
Many companies all over the world produce the new radio astronomy instruments, such as radiotelescopes: Green Bank (USA) with 100-meter diameter mirror, Plato Vilado (Spain) with 30-meter mirror and Suffa RT-70 (Russia) with 70 meters diameter mirror.

The accuracy of the angle position between the construction elements of a radiotelescope has to be very high. The research in the millimeter wave range requires the small (no more than 2 arc. seconds) deviation of the elements position relative to theoretic one.

The deformation of the radio telescope elements at the time of installation and at the research work period shows some problems [1].

The first problem comes during the installation period.

The error of angular orientation of an elevation axis relatively base axis causes the poor quality of radiotelescope. The limit error of measure angle Θ1 orientation elevation axis is less than 10 arc seconds at the measuring range as 10 arc minutes (figure 1).
The second problem shows up while radiotelescope works as a research instrument. The deformation of basic columns causes to angular displacement the axis bearing relative base of radiotelescope (figure 2).

As a result the elevation angle for a parabolic mirror orientation is not equal to values, which are set by the electric turn drive system on the base of the radio telescope.

The limit error of measure value $\Theta_2$ of the basic columns angular deformation is less than 2 arc seconds at the measuring region as 10 arc minutes (figure 2).

Analogy, the third problem arises at the period of radiotelescope research work too. A weight of mirror and a wind force causes to the angular deformation $\Theta_3$ of an axis bearing relatively a gyroscope platform of radiotelescope navigation system. At result the azimuth angle of a parabolic mirror axis orientation is not equal to values, which are set by the electric turn drive system (figure 3).

The limit error of measure value $\Theta_3$ the angular deformation is less than 2 arc seconds at the measuring region as 10 arc minutes (figure 3).

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**Figure 1.** The panorama of RT-70 Suffa installation. $\Theta_1$ is a elevation axis orientation angle.

**Figure 2.** The radiotelescope RT-70 Suffa (project). $\Theta_2$ is a basic columns deformation angle.

**Figure 3.** The radiotelescope scheme. $\Theta_3$ is a angular deformation.
2. Angular deformation and position control systems

Therefore it is necessary to realize the two special systems.

The first system measures the angular position of axis bearing relative the base of radiotelescope during the installation period and the period of radiotelescope functioning as a research instrument (the problems 1 and 2).

The second system measures angular deformation of an axis bearing relative a gyroscope platform of radiotelescope navigation system (problem number 3).

Semi-active optic-electronics measure instruments are used for the control of these angular deformations [2].

Their benefits are: the accommodation of a small-sized passive reflector as control mirror at the point of the measurement. The mirror angular displacements are measured by the autocollimator witch is placed on some the rigid base.

At the first system the autocollimator is located on the bases of radiotelescope construction. The controlled object is the axis bearing and the control mirror is placed on the back side of this axis bearing (figure 4). For a full control of the deformation the two similar optical–electronic channels are used. Each channel includes autocollimator and control mirror.

![Figure 4. The system for the angles $\Theta_1$ and $\Theta_2$ measure](image)

The working distance of optical-electronic system is 22 meters; the angle measurement range is 10 arc minutes.

In order to solve the third problem we used the optical-electronic system also. The autocollimator is located at the inside of the axis bearing, the control mirror is placed on the gyroscope platform of radiotelescope navigation system (figure 5) and for the entire control the two similar analogy optical–electronic channels are used.

In this case the working distance of optical-electronic systems is 15 meters, the angle measurement range is 10 arc minutes.

Usually such systems are based on the autocollimation method of measurement, but their working distance is less than 5 meters [3]. For this reason the realization of the autoreflection method of measurement is preferable.
3. Measurement system analysis

The scheme of autoreflection measurement system includes the objective 1 with focal length $f$, the control element (mirror) 2, the radiation mark 3, placed in front of the objective and the matrix photodetector 4 with microprocessor system for the image analyses (figure 6).

![Figure 6. The autoreflection method based system](image)

The optical-electronic autocollimator includes the elements numbers 1,3,4: it is connected to the rigid base.

The control element (mirror) 2 is located at the object of control. The mirror angular deviations as the object deformations are registered by the autocollimator.
The light beam scheme is shown in figure 7, in here the radiating and the receiving channels are shown separately.

The centre of the mirror is positioned at the control point O₁ same as in the autocollimation method based system, but the radiating mark 3 is placed in the exit pupil plane of the objective 1 (figure 7).

The mirror 2 forms the image 3a of the mark 3 symmetrically to the point O at the distance 2·L. The objective 1 (as receiver objective) projects the image 3a to a sensitive squire of the matrix photodetector 4. At a result, the image 3' of mark 3 is formed on matrix 4.

When the mirror 2 rotates on the angle Θ, the image 3a displaces on value \( X = L \cdot \tan(2 \cdot \Theta) \) in its plane. Accordingly, the image mark 4' on the matrix detector 4 shifts on value \( x = (X/2L) \cdot u' \).

The sensitivity of the measurement could be calculated as:

\[
S = \frac{x}{\Theta} = \frac{2 \cdot L \cdot f}{(2 \cdot L - f)}
\]

There is a special measuring error for the distance L more than 10 meters [4]. The reason of this error is the vignetting of the reflected beam part on the pupil of the objective. The vignetting part is G on the figure 7. According to the theoretical analysis it is the systematic error and so that the compensation algorithm can be used.

The algorithm of error reduction had been checked by the experiment on the model realization sample of the autoreflection measuring system.

4. Experiment description

Radiation mark image was destructed during the experiment due to vignetting. It’s shown on the figures 8 and 9. The Multiple measurement actions were made at each measurement point.

![Figure 8. Radiation mark image without vignetting](image)

![Figure 9. Radiation mark image with great vignetting](image)

The measuring channel includes the video-system: objective and CMOS-matrix as photo-detector. For processing of the video frames and calculation of control point coordinates the microcomputer is used. The video-system is a high accuracy device the type of OVI05610 Color CMOS QSXGA with 2592*1944 pixels (OmniVision), one pixel size is (2.8*2.8) \( \mu m^2 \) and the objective focal length is \( f = 500 \) mm.

The experimental data is shown on figure 9 as bars line. Measurement error due to vignetting rises to 36 arc. sec.

The statistic analysis of the experimental data allows to use trigonometric function for approximation and the approximation form is:

\[
\Theta_E = c \cdot \cos\left(\frac{x - a}{b}\right) + d
\]
The experimental research shows that the error contains the large determination part. This part of error has been approximated (the red line on figure 10). After special compensation the error of measuring becomes only 1.6 arc. second.

The experimental results demonstrate the possibility of the design the measurement systems with desired characteristics features.

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