Multi-matrix opto-electronic system for measuring deformation of the millimeter range radiotelescope elements*

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A novel optical instrument is proposed and studied to measure the deformation of each connection point for a mirror, which includes 24 multi-matrix base units and can be used in millimeter-scale signal reflection systems. Experimental investigations reveal that the error of measurement is σ=8.7×10^{-3} mm at a distance of 5 500 mm, which allows to measure the linear deformation of a radiotelescope with the mirror diameter of 70 m.

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The radar measurement system plays a significant role in detecting information about objects in the universe, and the radar signal with the wavelength at millimeter level is required. Many researchers are focusing on constructing the antenna mirror with large area to collect the signal in the millimeter range, such as NRAO 45 of Japan, LMT 50 of Mexico, SRT 64 of Italy, GBT 100 of U.S.A, FAST of China and so on. The reflection system radio-telescope system PT-70 (Suffa) of Russia also has a large antenna mirror, which is assembled by 1 200 pieces of reflectors, and the diameter of the mirror is 70 m[1,2]. The formation of a parabolic antenna surface needs a fairly high technical performance requirement, and each connection joint is easy to deform with the changes of temperature and gravity of antenna surface. The error caused by deformation can reach 30 mm. Therefore, a control system should be designed and used in the radar measurement system to compensate the deformation of sampling point of the parabolic antenna surface. The linear displacement in the relative standard state between the respective reflecting surfaces of the arc surface of the radar antenna is the key of this control system.

The preliminary remote high-speed measurement of object space coordinate information can be realized by the photoelectric instruments. Wu et al[3] proposed a novel laser theodolite measurement system based on non-orthogonal shaft to reduce the error of the measurement system. The accuracy is ±1 mm at Pauta criterion within the measurement radius of 3 m. A novel interferometric dual-frequency laser radar combines laser and radio detection and is suitable for both range and velocity measurement[4]. However, the measurement range limits its application in the reflection system PT-70 (Suffa). Wu et al[5] proposed a multi-heterodyne method using frequency comb and a tunable laser for absolute distance measurement. The non-ambiguity is up to 105 m by adjusting the comb repetition frequency slightly. However, the measurement accuracy only can be ensured within a range up to 30 m. In 2017, a long distance measurement up to 1.2 km on the outdoor baseline by an electro-optic dual-comb interferometry was realized[6]. Nevertheless, this measurement system is sensitive to temperature, and it is not conducive to measuring multiple parts at the same time.

In this paper, a novel optical instrument is proposed and studied to measure the deformation of each connection point for the mirror, which can be used in millimeter-scale signal reflection systems. This measurement system includes 24 multi-matrix base units. In the internal structure of the base unit, the long-focal-length lens and the CMOS matrix receivers are used to measure the linear displacement of the infrared light source at each connection point of the PT-70 reflection surface. Experimental investigations reveal that the error of measurement is σ=8.7×10^{-3} mm at a distance of 5 500 mm, which allows to measure the linear deformation of radiotelescope with the mirror diameter of 70 m.

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As shown in Fig.1, the system for the measurement of the main mirror deformation uses a sighting method and includes 24 multi-matrix base units, which are located on a base ring of the main mirror[1]. The base ring is next to the control surface with a diameter of 6 m, which is cast from iron with a thickness of 25 mm. The width of the base ring is 500 mm, and the axis coincides with the optic axis of the primary mirror. The base ring is an anti-deformation hard base with 24 base units attached to it. The objective lens of each base unit is opposite to the top of the control surface, and the optic axis of each mirror is arranged in 15°.

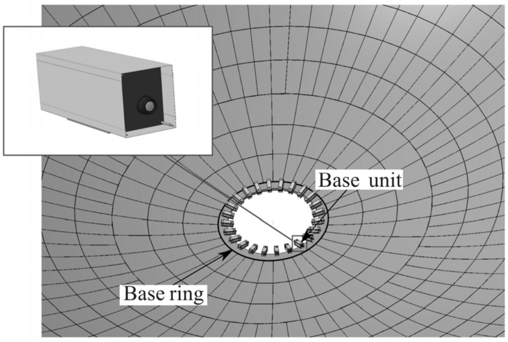

Fig.1 Structure of the main mirror measuring system

Each base unit includes the objective and 19 matrix photo-receivers as the image analyzers, as shown in Fig.2. Each base unit is capable of measuring 19 monitoring points on the antenna, and the entire measurement system in the base ring can monitor 456 detection points on the antenna. Therefore, it is possible to achieve a comprehensive detection of the linear displacement in the relative standard state between the respective reflective constituent faces of the antenna. Each detection point is a connection point of four mirrors, and it is necessary to fix point sources at the detection points as the targets. Then, the images formed by these point sources are focused by objective lens of the base unit to the CMOS. The CMOS matrix of each base unit is located at the conjugate image plane of the point source after the objective lens, so that the deformation of the corresponding monitoring point can be measured. For processing the video frame and calculating the control point coordinates, the computer is used.

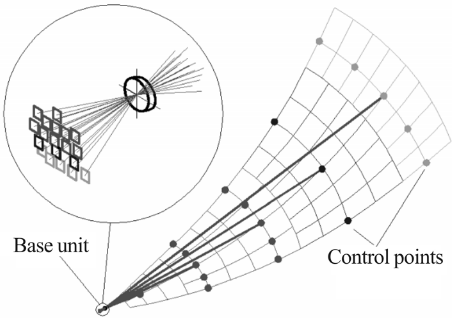

Fig.2 Structure of the multi-matrix base unit for the main mirror measuring system

The structure of the angle view for the control surface main mirror system is shown in Fig.3, and the angle view of these units displays the large part of the main mirror surface. The view fields of the base unit on the meridian plane and the sagittal plane of the control surface are $2\omega_1$=62° and $2\omega_2$=16°, respectively. The system consists of 24 base unit units. According to the shape parameters of the antenna for PT-70 (Suffa), this system can detect all control points on the control surface.

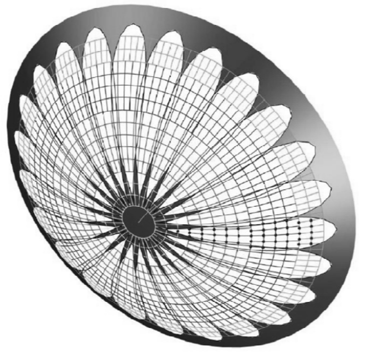

Fig.3 Structure of the angle view for the control surface main mirror system

The experimental setup of the base unit includes an infrared emission diode TSAL 4400 with power of 30 mW as radiation source, an objective with the focal length of 450 mm, and five CMOS matrix receivers (OV05620 Color CMOS QSXGA) with 2 592×1 944 pixels (pixel size is 2.2 μm×2.2 μm) produced by OmniVision as image analyzers. As shown in Fig.4, the designed experimental setup consists of the objective (position 8) with fasteners (positions 6, 7) and five CMOS matrix receivers (positions 10) with adjustment means (positions 9, 11, 12, 13, 14). The objective and matrix receivers are fixed on the base plates (positions 1, 2, 3). The three pillars (position 4) get the stiffness for design.

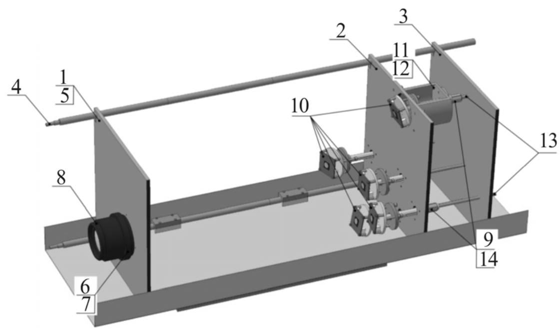

Fig.4 Schematic experimental setup of the multi-matrix base unit

To simulate the deformation of the surface for the radar antenna, the corresponding experimental platform is set up, which is shown in Fig.5, including a model machine to measure the base unit (1), a multi-dimensional laser measurement system XD^{TM} laser from Automated Precision Inc. (API) (2), a vibrator of Standa LTD (3), two optical sights (4) as infrared emission diodes TSAL 4400 produced by Vishay Intertechnology, one fixed and the other connected to the vibrator. The displacement of each connection point relative to the base unit on the CMOS can be calculated by

$$X=F(l) , \quad (1)$$

where X is the displacement of the image of the point source on the CMOS, and l is the displacement of the point source.

The measured shift $\widehat{l}$ of the optical sight is found by

$$\widehat{l} = \frac{X}{a} \cdot L \quad , \quad (2)$$

where L=5 500 mm is the distance from objective lens to optical sight, and a=490 mm is the distance from objective to CMOS matrix in an image space. The difference q is the measurement error:

$$q = \widehat{l} - l \quad . \quad (3)$$

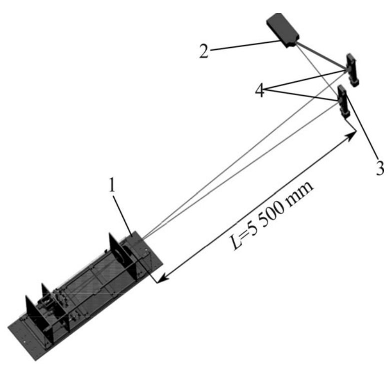

Fig.5 Schematic of the experimental setup

The image of the infrared laser moves through the optical sight in the 0—30 mm range with a moving interval of 3 mm. The displacement of the optical sight can be calculated from the coordinate center of the light source image on the base unit. The coordinate of each measurement point on the base unit's CMOS is taken for 100 frames to record the position information of the fixed sight and moving sight on the vibrator. The regression analysis is used to evaluate the performance of the base unit[7].

The experimental measurement result shown in Fig.6 is expressed as

$$\sigma=f(X), \quad (4)$$

where σ (in millimeters) is the root mean square (*RMS*) of the error q, and X is the shift of the image at pixels.

The maximum *RMS* is $\sigma=8.7\times10^{-3}$ mm for distance L=5 500 mm. The expected error for L=35 000 mm is 0.05 mm. The component design and experiments have shown an opportunity of making the large rotatable radiotelescope for researches in millimeter range.

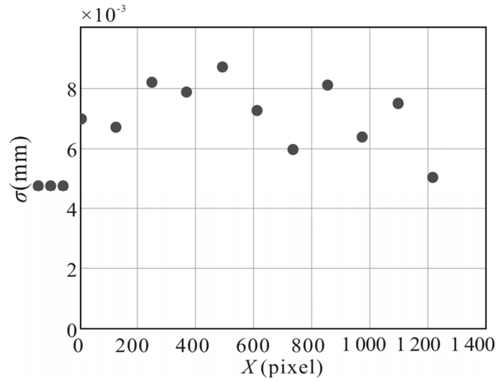

Fig.6 Measurement errors of coordinates for the optical sight

In this paper, a novel optical instrument is proposed and studied to measure the deformation of each connection point for a mirror, which can be used in millimeter-scale signal reflection systems. Experimental results reveal that the error of measurement is $\sigma=8.7\times10^{-3}$ mm at a distance of 5 500 mm, which allows to measure the linear deformation of radiotelescope with the mirror diameter of 70 m. The experimental and simulation results both achieve the performance requirements of measuring the linear displacement between the respective reflective components of the PT-7 antenna arc surface under the relative standard state.

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