Demarcation Technology on the Earth’s Field Angle of Collimating Infrared Earth Simulator

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Abstract. The size of Earth’s field angle is one of the most important parameters of Earth simulator. At present, this parameter can only be calculated by the way of optical calculation, and can not be tested exactly. Infrared detecting and optical modulation technique are introduced in the paper to demarcate the Earth’s field angle. The field angle demarcating system’s elements, general structure and measuring principle are all analyzed detailed in the paper. The small field infrared detector, the key element for demarcating field angle is discussed and analyzed theoretically and experimentally, and it can be seen from the experimental results that the Earth’s field size and shape is 0.41°×0.49° and ellipse respectively.

1. Introduction

Infrared Earth simulator is one of the testing equipment used in ground-based demarcating test of infrared Earth sensor. Demarcation technology on the field angle of earth simulator is a special technology on demarcate “collimating infrared earth simulator”. The disc’s angular diameter is the earth’s angle, which is the most important beacon. In order to meet the requirement of demarcation earth sensor, the precision value the earth field angle is an important fact [1, 2].

Demarcating technique of the Earth simulator is a special one for demarcating infrared Earth simulator [3-8], and the test for the Earth’s field angle is hard to realize in engineering. At present, there is no way to test the Earth’s field angle in our country, although Galileo Company of Italian is in a international advanced condition in satellite based on Earth simulator, it has no way in testing the Earth’s field angle and it can be only calculated with optical calculation. The demarcating method of Earth simulator is discussed in the paper, the suitable testing way in engineering is put forward and the demarcating system of the Earth simulator is also developed.

2. System constitution, general structure and angle testing principle

2.1. System constitution and general structure

Demarcating system of the Earth simulator consists of five parts: infrared detector of small field, optical modulator, electric testing box of the Earth signal, two-axis turret and computer controlling and data manage system. Demarcating system puts the five parts on the ground bracket, the Earth simulator put on the translation-gyration flat roof, the optical axis of infrared detector of small field
through the axis center of turret, the optical axis of the Earth simulator through the center of turret, and also perpendicular Y axis. The general construction of the whole demarcating system is as figure 1.

Figure 1. The general demarcating system structure of the Earth simulator field angle.

2.2. Field angle testing principle
The Earth can be considered as a disc from the satellite, and its boundary is horizontal, the disc angular diameter is the Earth field angle. The testing principle that when a thin beam is introduced to look at the Earth, if the beam rotating at a certain point which is the centre of a circle, and register the angle of entry or out, then the difference between the angles is the Earth’s field angle.

The way of demarcating the Earth’s field angle is use the infrared detector of small field to measure the output radiation of the Earth, if the direction of infrared detector is changed, the trapezoid wave of the Earth’s output can be obtained. With the middle point of the trapezoid we can obtain the Earth’s hypotenuse width, and then the Earth’s field angle can be obtain from that, the principle of this system can be shown in figure 2.

Figure 2. The principle frame scheme of demarcating set of the Earth simulator field angle.

3. Theoretical analysis and design for infrared detector of small field
Infrared detector of small field is the key element to demarcate the Earth’s field angle of the Earth simulator. When a thin beam is used to measure field angle, the obtained Earth wave is rectangular. We hope that the field angle of infrared detector is small enough to meet the need of demarcating field angle of the Earth simulator. But the small field angle will reduce the signal noise rate of demarcating element. When a certain size field angle is used, the Earth wave obtained is actually a trapeziform with the hypotenuse width inverse ratio to the size of field, which can cause some measuring error. In order to reduce this measuring error, the field of detector should be small enough and the signal noise rate should be high enough, or the noise will influence measuring precision. When we design the infrared detector of small field, the way of smallest spherical aberration can not be used for designing infrared optical system whose operating wave band is from 14 micrometer to 16.25 micrometer in order to result the smallest dispersed spot and can receive the whole beams of the field. Super-hemispherical immersed lens is introduced in the paper, and the small field optical system is also designed to meet the need of testing field angle.
3.1. The design of infrared optical system

The infrared optical system of small field consists of meniscus lens, immersion lens, thermal resistance infrared detector and stop, and its main optical is meniscus lens whose performance and structure serve a very important function, see figure 3. The focal length $f'$ should be regarded as the principle to design the smallest spherical aberration, and the best scheme can be obtained through optical calculation.

![Figure 3. The infrared optical system of small field.](image)

3.2. The selection and calculation of meniscus lens focal length ($f'$), radius ($r_1, r_2$)

In the optical system of figure 4, B is a meniscus whose clear aperture is D, focal length $f'$. The semi height of the object at infinite $a_1$ imaging on meniscus lens plane with field angle is $2\omega$, and is semi height of $a_1$ immersed by lens.

![Figure 4. Infrared optical system.](image)

From figure 4, we can see
\[
\frac{\alpha_1}{\alpha} = f' \cdot \frac{\tan \omega}{\omega} \quad (1)
\]
\[
G = \frac{\alpha_1}{\alpha} = \frac{1}{f'} \cdot \frac{\tan \omega}{\omega} = \frac{D}{\alpha} \cdot \frac{\tan \omega}{\omega} \quad (2)
\]

Where $G$ is immersion gain, $F = \frac{f'}{D}$, according to the smallest spherical aberration expression, and assume refractive index $n \approx 4.00137$, then
\[
\frac{r_1}{r_2} = \frac{4 + n - 2n^2}{n(1 + 2n)} \approx \frac{2}{3} \quad (3)
\]

Meniscus lens radius $r_1, r_2$ and thickness $d_1$ can be obtained from optical calculation. When optical system works in the air, then $n_0 = 1.0$, and the focal length $f'$ can be expressed as follows
\[
\frac{1}{f} = \frac{(n - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) + (n - 1)^2 d_1}{n_0 r_1 r_2} \quad (4)
\]

3.3. The design of immersion lens

The immersion lens is in the convergent system, and its position and size of curvature radius will influence aberration and structure of main optical system. Aperture angular $\alpha'$ should be the biggest when design the immersion lens, and then imaging plane will obtain the most luminance. This design also can improve the detector’s signal noise rate and immersion gain, reduce the detector’s sensitive plane area, all the above are very important in designing an infrared optical system of small field.
3.4. Optical path calculation
Select optical system parameters as \( r_1 = 240 \text{mm}, \ r_2 = 360 \text{mm}, \) curvature radius of immersion lens \( r_3 = 5.5 \text{mm}, \ d_1 = 2.15 \text{mm}, \ d_2 = 230.5 \text{mm}, \ d_3 = 6.707 \text{mm}, \) clear aperture \( \Phi_0 = 24 \text{mm}, \) detector’s size \( 0.13 \text{mm} \times 0.13 \text{mm}, \) then \( f' = 236.7093057 \text{mm}, F = 0.9862887738, \) making ray tracing for different incoming height \( h \) and different incident angle \( u, \) we can see from the above, when field angle \( 2\theta = \pm 0.067^\circ, u = 0^\circ, \) all incoming rays can get the sensitive plane of detector, so the design method is correct. Optical system aberration curve and spot diagram for infrared detector of small field can be expressed as shown in figure 5.

(a)spherical aberration curve(on-axis)  (b)curvature and distortion curve

Figure 5. Optical system aberration curve for infrared detector of small field.

4. Demarcating experiments and results of infrared detector of small field
A stop is set in the focal point of paraboloid off-axis reflective collimator; behind the stop are black body and modulator, the function which is to bring a modulated parallel beam with an angle no more than \( 6^\circ. \) The infrared detector of small field is set on the two-axis turret and the detector is an infrared telescopic lens, see figure 6. Parallel beam forms image on the thermal sensitive resistance of detector’s focal plane and the output signal of detector is a voltage signal. When imagine is on the boundary of field, output voltage magnitude is about a half of peak value, and then the boundary of field can be obtained.

Figure 6. Field demarcating set for infrared detector of small field.

The demarcating curve of infrared detector of small field in X direction, Y direction and full filed of view field angle is shown in figure 7 and 8.

Figure 7. Field angle demarcating curve of infrared detector of small field in X,Y direction.
Figure 8. Field angle demarcating curve of infrared detector of small field in full field of view.

The experimental result of infrared detector of small field is a paraboloid field of $0.41^\circ \times 0.49^\circ$. The signal can also meet the need for detecting thermal radiation signal of the Earth simulator.

5. Conclusion

The demarcating way and experimental system of the Earth simulator field angle in the paper have practical purport and applied value. With optical modulating technique we can converse invariable radiation emitting from the Earth simulator into sinusoidal one, and we can also translate infrared detector’s output into AC signal. With selective frequency amplifier and low frequency filtering technique we realized small signal low noise amplifier, and improved data collecting and processing precision. The infrared detector of small field realized demarcating the Earth simulator field angle cooperating with two-axis turret and computer controlling and data processing system, and this provided a way for testing the Earth simulator field angle. The actual applied results show that the above method for demarcating the field angle of the Earth simulator is suitable and correct.

The demarcation method on infrared detector of small field was also put forward in the paper, using this method we can realize the demarcation for infrared detector of small field, and this was cited by experiments, this method also gives an effect measuring for other infrared optical system field.

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