Research on directional responsetest of pyranometer

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Abstract: Directional response is one of the most important parameters of pyranometer, which is crucial to evaluate the performance of the pyranometer by determining the responsivityand the corresponding radiation for solar beam radiation from different directions of the pyranometer. In the paper, the method for testing directional error is present, four pyranometers are tested, after data processing, the directional errors of a secondary standard CMP22 and a first class CMP11 are 4.5 W/m^2 and 8.3 W/m^2 respectively, which are within the nominal specification given by the manufacturer. Meanwhile, the directional error of a first class pyranometerFS-S6 is 11.0 W/m^2, while the value of a second class pyranometer TBQ-2-B is15.2 W/m^2, which both meet the specification for classification. The results show that these four pyranometers can reach the levels recommended by WMO and ISO, which validates that the method is feasible and the China made pyranometers are reliable.

Key words: pyranometer, directional response, test, classification

1 Introduction

Accurate solar radiation data are widely used in meteorology and solar energy developing fields. For solar radiation measuring instruments, especially pyranometer, directional response is an important factor that affects the accuracy of the instrument. As we all know, the sun's trajectory is changing with daytime while the pyranometer is remaining unchanged, so the responsivity of the pyranometer would be a variable when the sunlight projects from different directions, which may cause directional errors. According to International Standard Organization (ISO) 9060(1990), the directional response of a pyranometer is defined as the responsivity for beam radiation as a function of the direction of the incident radiation related to the pyranometer, which can be characterized to directional error, one of many parameters that classifies different pyranometers. The same as ISO 9060, <<Guide to Meteorological Instrumentsand Methods of Observation>> issued by World Meteorological Organization (WMO) and-Commission for Instrumentsand Methods ofObservation (CIMO, 2008) also classify thepyranometers with directional errors. For ideal pyranometers, the directional error should not exist, which means the ratio of the signal to the irradiance related to direction is zero andindependent to the direction. However, because of the manufacturing process and equipment, the directional error is hardly eliminated. Therefore, in order to assess and classify pyranometers, the directional error of pyranometers must be tested beforehand.

Methods for testing the directional response can be retrieved from many documents. In JJG 458-1996Verification Regulation of Pyranometer (1996) and National Standard GB/T 19565 (2017), the directional response is divided into two parts, one is cosine response, which is characterized to the responsivity for beam radiation as a function of the zenithangle of the incident radiation relative to the pyranometer, it can be tested in 80° zenith angle with respect to the vertical direction of the incident radiation using the solar simulator, the irradiance for testing should not be less than 500W/m^2, the other one is azimuth response, which refers to the change in

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the responsivity caused by the change of the azimuth angle of the incident radiation, the test procedure isputtingthepyranometer under the incident radiation from 80° zenith angle, changingtheazimuth angle to 60°, 90°, 120°, 240°, 270° and 300° in sequence, then calculating the error of each responsivitywith respect to the average of the six responsivityvalues, finally, the max error is selected to be the azimuth response error (Bian et al.). Similarly, ISO 9060 issued in 1990 also addressed the specification and testing method of directional response, according to ISO 9060, the measurement must be made of responsivity relative to normal incidence at incident angles of 30°, 40°, 50°, 60°, 70° and 80° at 12 azimuth angles 0°, 30°, 60°, ⋯and 330° under the incidence irradiance at 1000W/m^2. Obviously, the two methods are the same in essence but different in incidence angles and calculating process.

In this paper, a simplified method with respect to the method in ISO9060is present, which has less incident angles and less azimuth angles, four different pyranometers manufactured both by Chinese companies and foreign companies in different classes are tested using the equipment for laboratory testing of solar radiation measuring instruments, through data quality control, 64 data are obtained, the data processing result shows that four pyranometers are classified into the corresponding ranks given by the manufacturers, which validates that the simplified method isfeasibleandthe quality of China made pyranometer is reliable.

2 Test Method

According to the definition, directional responserefers to the errors related to different directions of the incident radiation, so we need to simulate the solar radiation and change the direction of the solar radiation, then measure the responsivity related to normal incidence at different zenith angles and azimuth angles. In this study, we set 40°, 60°, 70° and 80° as four zenith angles, ateach zenith angle, measurement of the responsivity must be collected at four azimuth angles 0°, 90°, 180°, and 270° respectively, here the azimuth angle 0° represents the direction of the cable outlet of the pyranometer, then calculate the error of responsivityrelative to normal incidence, thus the directional response can be obtained.

Therefore, the equipmentused for simulating the solar position is the key for testing directional response, in this study, a JJF II-200equipmentfor laboratory testing of solar radiation measuring instruments (Lu and Mo, 1996) is used, the structure is shown in Fig.1.

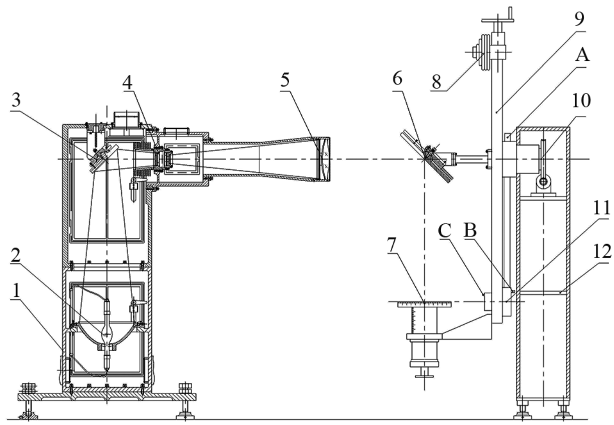


Fig. 1 The JJF II-200 Equipmentfor laboratory testing of solar radiationinstruments

1- Housing, 2 - light source room, 3 - turning plane mirror, 4 - optical integrator, 5 - collimating optical system, 6 - steering plane mirror, 7 -instrument mount, 8 - balance weight, 9 - tumbler, 10 - reduction gearbox, 11 - clutch mechanism, 12 - framework

The JJF II-200 consists of a solar simulator and a rotating mechanism with an instrument mount, the irradiance of the solar simulator ranges from 250W/m^2 to 1250W/m^2, the non-linearity of the radiation is ±1% within an effective area in radius of 60mm, the stability of the radiation is ±0.5%/h and the spectrum of radiation is in accord with AM 1.5, all of these technologies make the directional response test to be a reality (Lu et al, 2013 and Wanget al, 2013). According to ISO 9060, the directional response can be specified as an absolute error, so with the help of the JJF II-200 equipment for laboratory testing of solar radiation measuring instruments and the controlling computer, laboratorymeasurements of directional response are made under the pyranometer-exposing to invariable beam radiation while changing the direction of the incident radiation relative to the pyranometer, then the signal can be collected as a function of the direction used for directional error calculation (Lu et al, 2001 and Lu et al, 2013). The method of testing directional error can be specified as follow steps:

(1) Turn on the power of JJF II-200 equipment, set the zenith angle to be 0°, make the output irradiance into constant irradiance of 1000W/m^2, put the pyranometer on the instrument mount, the cable direct to the north, adjust and keep the pyranometer level, fasten it, as shown in Fig.2;

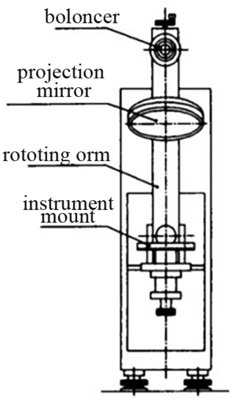


Fig. 2 The status of simulating the sun atzenith angle of 0°

(2) When the signal output is stable, start to collect the data, the sampling interval and time can be setup as the need, in this study, we sample the signal in every 10s for 100s, get 10 points in normal irradiance (Lu et al, 2015 and Lyu et al, 2015);

(3) Turn the tumbler and the instrument mount, adjust the zenith angle to 40°, adjust and keep the pyranometer level, now the azimuth is 0°, as shown in Fig.3, after the output signal is stable, record the signal in the same sampling interval and time as (2);

(4) Setup the azimuth angle into90°, 180°, and 270° in sequence, rotate the instrument mount to implement it, adjust and keep the pyranometer level, collect the signal in the same sampling interval and time as (2) at each azimuth angle of 90°, 180°, and 270°respectively;

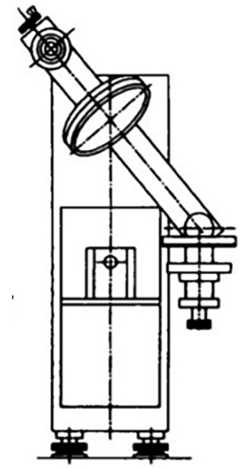


Fig. 3 The status of simulating the sun at zenith angle of 40°

(5) Reset the azimuth into 0° and the zenith into 0°, adjust and keep the pyranometer level, collect the second 10 points in normal irradiance in the same sampling interval and time, then the average of the two 10 points in normal irradiance served as the finally normal irradiance.

(6) set the zenith angles into 60°, 70° and 80° in turn, repeat the steps (2)-(5), obtain the data at the zenith angles of 60°, 70°and 80°.

The "1000W/m^2 directional error" can be calculated with the collected signal by Equation (1) (ISO, 1990):

$$\Delta_{1000}(\theta,\ \psi) = 1000 \times \left[\frac{s(\theta,\ \psi)}{s(\theta=0)} - \cos\ \theta \right] \quad (1)$$

Where:

$\Delta_{1000}(\theta,\ \psi)$ is the 1000 W/m^2 directional error, (W/m^2);

$\theta$is the zenith angle, $\theta = 0°$ is normal incidence, (°);

$\psi$is the azimuth angle, $\psi = 0°$ represents the direction of the cable outlet of the pyranometer, (°);

$s(\theta, \psi)$ is the signal, $s(\theta = 0)$ is thesignal response to normal incidence, (V).

Both in CIMO Guide andISO 9060, the $\Delta_{1000}(\theta,\ \psi)$ is one of numerous parameters chosen to classify the pyranometers, the specification is given in Table 1.

Table 1 Pyranometer specification of directional response

Specification	Pyranometer classification		
	Secondary standard	First class	Second class
Directional response	± 10 W/m^2	± 20 W/m^2	± 30 W/m^2

From Table 1 we can see, there is only one directional error value all overthe directions for each pyranometer of different classes, moreover, this directional error $\Delta_{1000}(\theta, \psi)$ is measured under the irradiance of 1000W/m^2, because the solar beam radiation values arerarely bigger than 1000W/m^2 on the surface of the earth, $\Delta_{1000}(\theta, \psi)$ would be the maximum error related to the directional response of the pyranometer, therefore, it is an accurate index to classify pyranometers.

3 Test Result and Analysis

According to the method given in section II, four pyranometers in different classesare tested in the paper, the information of these four pyranometersis shown in Table 2. Compared with Table 1, the directional errors of CMP22 and CMP11 given by theforeign manufacturer are better than the specifications in the CIMO Guide and ISO 9060, while China made FS-S6 and TBQ-2-B are the same with the specifications in the Table 1.

Table 2 Information of four pyranometers

Type	Serial No.	Directional error (at 80° with 1000 W/m^2 irradiance)	Class given by manufacturer
CMP22	100180	±5 W/m^2	Secondary standard
FS-S6	1405.0062	±20 W/m^2	First class
TBQ-2-B	2254	±30 W/m^2	Second class
CMP11	115779	±10 W/m^2	First class

After data quality control process, there are 64 data left to analysis. According to Equation (1), the directional errors of CMP22 100180, FS-S6 1405.0062, TBQ-2-B 2254 and CMP11 115779 are shown in Fig.4, Fig.5, Fig.6 and Fig.7, respectively.

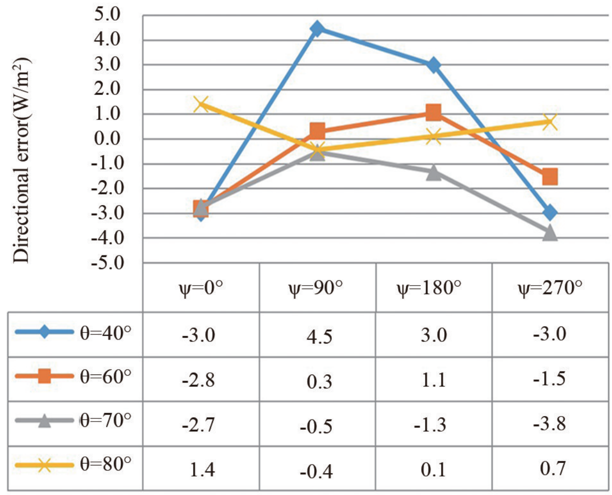


Fig. 4 Directional error curve of pyranometer CMP22 100180

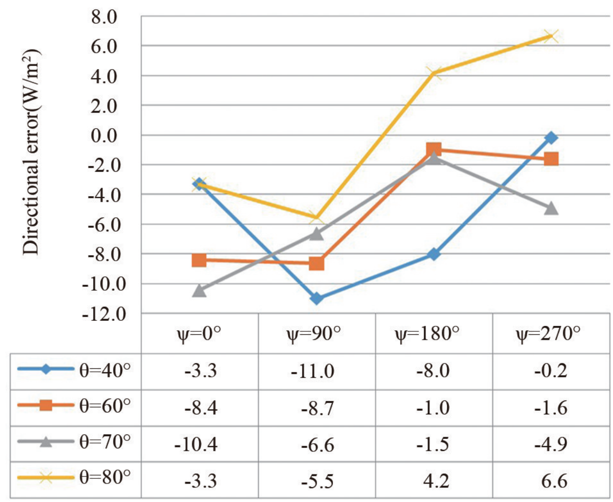


Fig. 5 Directional error curve of pyranometer FS-S6 1405.0062

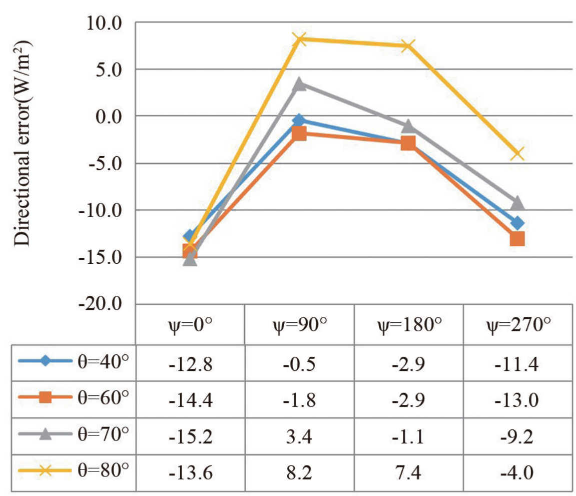
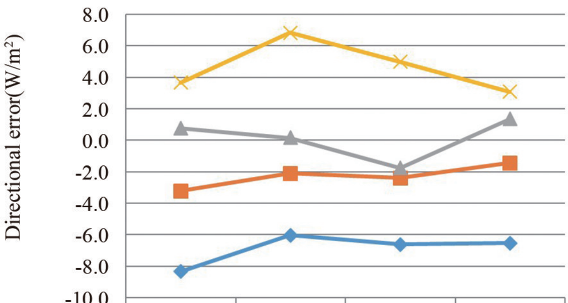


Fig. 6 Directional error curve of pyranometer TBQ-2-B 2245



	ψ=0°	ψ=90°	ψ=180°	ψ=270°
θ=40°	-8.3	-6.0	-6.6	-6.5
θ=60°	-3.2	-2.1	-2.4	-1.4
θ=70°	0.7	0.2	-1.8	1.3
θ=80°	3.7	6.8	5.0	3.1

Fig. 7 Directional error curve of pyranometer CMP11 115779

Asthe CMP22 100180 is a secondary standard, of which nominal directional error is less than ±5 W/m^2, we can see that the maximumabsolute value of directional error of No. 100180 is 4.5 W/m^2 at the zenith angle of 40° and the azimuth angle of 90° in Fig.4, which validates not only theperformance of CMP22, but also the feasible of the method. Meanwhile, as we all know that the cable of thepyranometer in operational use is face to north, namely the azimuth angle ψ= 0°, while ψ=90° is inthe morning, ψ=180° is at noon and ψ=270° is inthe evening, so when ψ= 0°, no matter what the value of zenith angle θis, the directional error of the pyranometer is meaningless, we should only focus on the directional errors at the azimuth angles of 90°, 180°, 270°, especially when ψ=90° and 270°, we need to pay attention tothe directional errors at big zenith angles like θ=80°, because ψ=90°and 270° are responding to morning and evening time respectively, at that time, the elevation angle of the sun is low and the solar radiation is small, which will lead to bigger directional errors (Mo et al, 2009 and Lu et al, 2012). From Fig.4, the absolute value of directional error at θ=80°can meet the requirement in the Table 2. When ψ=180°, it is at noon time, the sun is high and the radiation is big, at this time, the directional error is related to low zenith angles, from Fig.4, the result can meet therequirement.

The pyranometerFS-S6 1405. 0062 is a first class pyranometer made by China, of which directional error should be less than ±20 W/m^2.From Fig. 5, the maximum absolute directional error of No. 1405.0062 is 11.0 W/m^2 at the zenith angle of 40° and the azimuth angle of 90°, the same with CMP22 100180 and the most important points at azimuth 90° and 270° of zenith angle 80° are within the acceptable limits (Lu, 2008).

The pyranometer TBQ-2-B 2245 is a second class pyranometer made by China too, the directional error of which should lie in ±30 W/m^2. From Fig. 6 we can see that the biggest absolute directional error of No. 2245 is 15.2 W/m^2 at the zenith angle of 70° and the azimuth angle of 0°, which meets the requirement parameter perfectly, the same results of other angles are listed in Fig.6. Although TBQ-2-B is a nominal second class pyranometer, the directional error of No. 2245 is within the specification of first class pyranometer, we can use it as we need.

Fig.7 is the directional error curve of the first class pyranometer of CMP11 115779, which has the same manufacturer with CMP22, the directional error of which should be less than ±20 W/m^2. From Fig.7, the biggest absolute directional error of No. 115779 is 8.3 W/m^2 at the zenith angle of 40° and the azimuth angle of 0°, which is within the requirement given by the manufacturer, CIMO Guide and also ISO 9060. Meanwhile, for the No. 115779 pyranometer, we can see thatthe directional errorsare greatly relative to the performance at lowsolar zenith angleof 40°, because when at solar zenith angle of 80°, the directional errorsof No. 115779 are 6.8 W/m^{2}and 3.1 W/m^{2}respectivelyat the azimuth angles of 90° and 270°,which are smaller than the error measured at the zenith angle of 40°. Even so, all of the directional errors at different angles are within the requirement of CMP11 specification and better thanthe specification used for classification in Table 1.

4 Conclusion

Directional response is a very important parameter for pyranometer performance, which refers to the responsivity for beam radiation as a function of the direction of the incident radiation relative to the pyranometer, especially for the performance when the sun is low and the solar radiation is small. According to the CIMO Guide and ISO 9060, in this paper, the method for testing directional error is present and four pyranometers in different classes are tested, after data processing, the directional errors of the secondary standard CMP22 100180 and the first class CMP11 115779 are 4.5 W/m^2 and 8.3 W/m^2 respectively, which are within the nominal specification given by the manufacturer, better than the specification listed in CIMO Guide and ISO 9060. Meanwhile, the directional error of the first class pyranometerFS-S6 1405.0062 is 11.0 W/m^2, while the value of the second class pyranometer TBQ-2-B 2245 is15.2 W/m^2, both of these two pyranometers are China made product, the directional errors of which are in the range of specification used for classification. All the results show that the method used to test directional response is feasible and the pyranometers are reliable.

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