Development and Application of Working Standard Pyranometer

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Abstract: Using the temperature compensation and structure optimization design technology, developed the TBQ-2-B type standard pyranometer on the original pyranometer basis, its stability is better than 2%, reached the international standard ISO 9060 and the World Meteorological Organization (WMO) instruments and methods of observation Committee (CIMO) on the first level pyranometer request. Over the years, comparing with our national solar radiation standard (absolute cavity radiometer), its performance is very stable. As a working standard pyranometer, it has been used for more than twenty years in the field of metrological calibration of meteorological radiation instruments.

words: working standard pyranometer, development, applicat

1 Introduction

Radiation measurements are used for studying thetransformation of the energy within the Earth-atmosphere system and its variation in time and space; It can be used for analyzing the properties and distribution of the atmosphere, such as aerosols, water vapor, ozone and so on; It also can be used for studying the distribution and variation of incoming, outgoing and net radiation; This will satisfy the needs of biological, medical, agricultural and industrial activities, At the same time, satellite radiation measurements and algorithms can be verified. Therefore, solar radiation is an important part of meteorological observation (ISO 9060, 1990).

In order tomeet the needs of the metrological verification service of solar radiation measuring instruments, the development of the standard pyranometer was carried out, and the development plan was established on the basis of plenty researches and experiments. Based on the original pyranometer, with the help of temperature compensation and structure optimization design technology, the TBQ-2-B type standard pyranometer was developed , its stability is better than 2%, reached 9060 ISO and the World Meteorological Organization (WMO) and Commission for Instruments and Methods of Observation (CIMO) requirements of the first level of pyranometer (CIMO 2010 and GB/T 19565 2017). Compared with national solar radiation standard, its performance is very stable. As a working standard pyranometer, it has been used in the field of metrological calibration of meteorological radiation instruments.

2 Principle and Structure

2.1 Measuring Principle

The inductive part of the working standard pyranometer is the core part of the instrument. It consists of an induction surface and a thermopile, the induction surface is made of sheet metal coated with a matt black paint with high absorptivity and good spectral response. The thermoelectric materials were made of copper constantan pile which clings to the bottom of the induction. It is insulated from the induction surface (conduction heat without conduction electricity) to avoid short circuit.

When the radiation source (such as the sun) irradiation on the pyranometer, the induction surface absorbs the radiation energy and increases the temperature, then the thermoelectric thermopile at the lower part of the induction surface generates electromotive force. By measuring the electromotive force, the measured irradiance can be obtained after conversion. The principle of the thermoelectric radiometer is shown in figure 1.

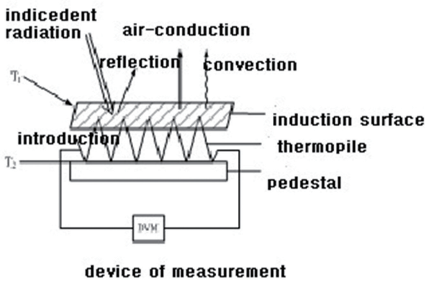

Fig. 1 Principle of radiometer

When the induction surface receives the radiation and reaches balance, it can be expressed as:

$$E = (1\text{-}\varepsilon)E + H_2(T_1\text{-}T_2) + L(T_1\text{-}T_3) + f(V) \quad (1)$$

In the formula, E represents incident radiation; εrepresents absorption rate of induction surface; H_2 represents a heat conduction coefficient of transmitted to the cold end; L is heat conduction coefficient of transmitted to the air; V is wind speed, $f(V)$ represents heat quantity of convection loss; T_1 is the temperature of induction surface (temperature of the hot end); T_2 is the temperature of cold end; T_3 is air temperature. The first item on the right side of the formula is the reflected loss of heat; the second is the heat transmitted to the cold end; the third is the heat transmitted to the air; the fourth is the heat of the convective loss.

In formula (1), the heat loss due to long wave radiation of the induction surface is omitted. If the induction surface is covered with glass dome, wind speed in the glass domes zero V = 0, then $f(V) \approx 0$.

If $T_2 = T_1$ is assumed, while H_2, L, $\varepsilon$is fixed numerical value as a same instrument, the formula (1) can be rewritten as:

$$E = \frac{H2 + L}{\varepsilon}(T_1\text{-}T_2) = A(T_1\text{-}T_2) \quad (2)$$

Then $A = \frac{H2 + L}{\varepsilon}$

Therefore, the size of the irradiance E depends on the temperature difference between the hot and cold ends (T_1-T_2).

The electromotive force produced by the temperature difference between the hot and cold ends is:

$$V = nE_0(T_1\text{-}T_2) \quad (3)$$

In the formula, E0 is the thermoelectric conversion coefficient(μV/℃). To substitute (T1-T2) in formula (3):

$$V = nE_0\left\{\frac{\varepsilon}{H_2 + L}E = KE\right\} \quad (4)$$

so $K = nE_0\left\{\frac{\varepsilon}{H_2 + L}\right\}$

In the formula, K is known as the sensitivity of pyranometer, unit ($\mu V \bullet W^{-1} \bullet m^2$).

According toformula (4), if the irradiance is stronger, the temperature difference of the thermopile of the radiometer is bigger and the electromotive force of the output is greater. Thus, the magnitude of the irradiance can be known through measuring the magnitude of the electrical signals produced by the radiometer.

2.2 Instrument Structure

The pyranometer is an instrument for measuring the total solar radiation. It consists of an induction device, a glass dome, an anti-radiation plate, a desiccant and a horizontal adjustment mechanism and so on. The induction device is composed of an induction surface and a thermopile. When the induction surface receives radiation heat gain, the thermopile generates a temperature difference electromotive force, the magnitude of electromotive force is proportional to the received irradiance. The glass dome is a hemispherical double layer quartz glass, which can resist wind and radiate short wave radiation ranging from 0.3 to 3 μm. The radiation protection board is white, which can block the heating of the lower part of the instrument by the solar radiation and reduce the radiation effect bellowing the horizontal plane of instrument on induced surface. Desiccant can keep air dry in the glass dome. The horizontal adjustment mechanism ensures that the sensing surface remains level (JJG 485 1996 and LV, MO 2002). The diagram of the pyranometer structure is shown in Figure 2. The appearance of the pyranometer is shown in figure 3.

The induction device is composed of an induction surface and a thermopile, when the induction surface receives solar radiation to increase heat, a temperature difference electromotive force is generated at the two ends of the thermopile, and the magnitude of electromotive force is proportional to the amount of radiation received by the induction surface. By measuring the voltage signal, the total solar irradiance can be calculated by dividing the sensitivity coefficient. The pyranometer is equipped with level bubble, and the horizontal adjusting bolt can be used to ensure that pyranometer is in a horizontal state. A dryer is provided inside the pyranometer to prevent moisture condensation.

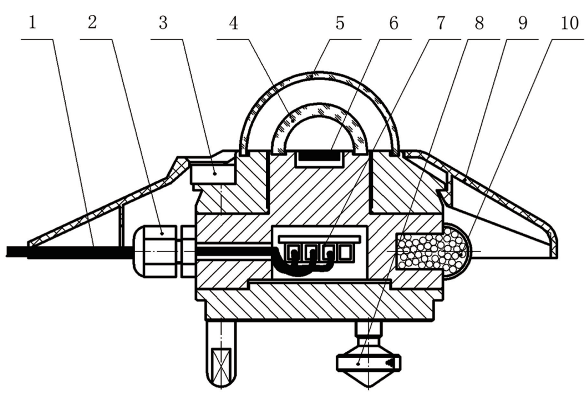

Fig. 2 Structure representation of pyranometer
1-electric cable 2-connection port 3-level bubble
4-inner glass dome 5-outer glass dome
6-induction device 7-processing circuit
8-Horizontal adjusting bolt 9- Radiation plate 10-dryer

Fig. 3 TBQ-2-B working standard pyranometer

3 Key Technology

In the development process, performance including response time, zero offset, cosine response, response range, temperature characteristics, nonlinear, resistance and sensitivity of TBQ-2 type pyranometers used in meteorological station were tested. By testing and analyzing, the conclusion is that, the temperature response, cosine response and azimuth response characteristics of TBQ-2 type pyranometer cannot meet the requirements of first lever pyranometer described in ISO. Therefore, a series of experiments have been done to validate the above performance of the pyranometer, the structure design of pyranometer was optimized, mainly in size and processing technology of double glass dome, induction surface and ambient light bar. According to the test results, the temperature compensation circuit was added. On the basis of TBQ-2 type pyranometer, the TBQ-2-B type working standard pyranometer was developed, it meets ISO 9060 and the World Meteorological Organization (WMO) and Commission for Instruments and Methods of Observation (CIMO) requirements of the first level of pyranometer.

4 Long-term Stability and Application of the Instrument

4.1 Long-term Stability of Instrument

The long-term stability of the instrument is the comprehensive performance of key performance indicators, by comparingwith national solar radiation standard in different temperatures, different irradiance, different height of the sun conditions every two years, the performance of TBQ-2-B type standard pyranometer is stable (THEKAEKARA 1976, CMA 1996 and FRÖHLICH, LONDON 1986), its sensitivity changes less than 2%, the main technical indicators, such as the direction of instrument response, temperature characteristics, nonlinear, tilt response (LV, MO and YANG 2001) and spectral selectivity can satisfy the requirements of first-level pyranometer stipulated by ISO 9060-1990 and WMO

CIMO instruments and methods of observation guide (CIMO 2010 and GB/T 19565 2017). The TBQ-2-B pyranometer has remained stable and reliable (see Figure 4, figures 5 and 6) since 1994, it has been used as a working standard pyranometer in the meteorological verification service, and it has also been used as a transfer standard of total solar radiation.

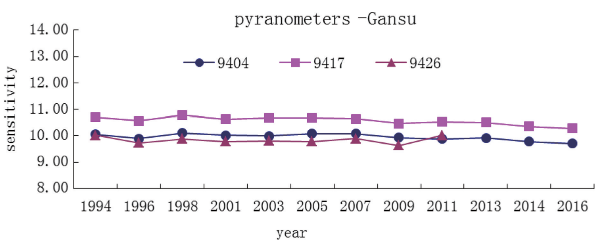

Fig. 4 long-term stability of working standard pyranometer in Gansu

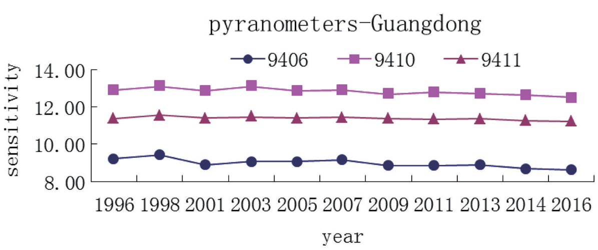

Fig. 5 long-term stability of working standard pyranometer in Guangdong

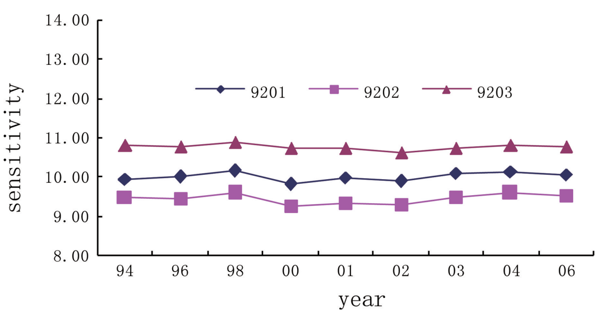

Fig. 6 long-term stability of working standard pyranometer in National Meteorological Metrological Center (Beijing)

4.2 Application

Since 1994, China has established eight regional radiation instrument verification, they are Heilongjiang, Xinjiang, Gansu, Tibet, Zhejiang, Guangdong, Yunnan province (District) meteorological station and the National Meteorological Metrological Center (Beijing), each center is equipped with 3 TBQ-2-B type working standard pyranometers, which formed a group of provincial radiation standard of China. They are responsible for the preservation and use of these working standard pyranometers, and carry out the metrological verification work of pyranometers. Through the Technical Supervision Bureau assessment, each station has obtained the measurement standard examination certificate.

5 Conclusion

Through temperature compensation and structure optimization, the TBQ-2-B working standard pyranometer has been developed. The stability of sensitivity is verified to be less than 2% by comparison with absolute pyrheliometer. More than 20 years' service in meteorological field, it shows that the performance of the instrument is stable and reliable.

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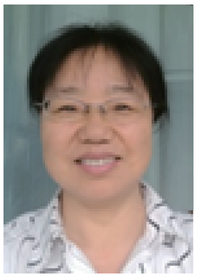
Authors' Biographies



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