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Tilt response of pyranometers — studies at Pune

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सार — प्रायः पाईरेनोमीटरों का प्रयोग क्षैतिज स्थिति में किया जाता है और इनसे सूर्य और आकाश से निकलने वाली भूमंडलीय सौर किरणन ऊर्जा को मापा जाता है। सौर ऊर्जा रूपांतरण के संस्थानों की क्षमता का पता लगाने के लिए ढलवें कोणों पर पाईरेनोमीटरों का प्रयोग करने के कारण नत स्थितियों के प्रभाव का अंदाज लगाया जाता है। पुणे की केन्द्रीय विकिरण प्रयोगशाला ने अपने साधन जुटाए हैं और विभिन्न ढलवे कोणों पर विभिन्न पाईरेनोमीटरों के कार्य निष्पादन के माप लिए है। उनके परिणामों की चर्चा इस शोधपत्र में की गई है।

ABSTRACT. Pyranometers are normally used in a horizontal position to measure the global solar irradiance from the sun and sky. Because of the use of the pyranometers at sloping angles for determining the efficiency of the solar energy conversion installations, the effect of the tilted positions have to be quantified. Central Radiation Laboratory at Pune has made its own device and made measurements of the outputs of different pyranometers at different sloping angles. The results are discussed in the paper.

Key words — Pyranometer, Irradiance, Tilt angle.

1. Introduction

One of the most important characteristics, which affects the performance of a pyranometer, is the non-adherence to or more explicitly the deviation from the cosine law of response of the pyranometer with reference to the angle of incidence of irradiation. When the pyranometer is used in other than the horizontal position, the physics of the energy exchanges becomes more complex leading to some serious errors in the directional response of the pyranometer. According to (Fröhlich 1986), the errors due to deviations from cosine response may become more serious in tilt positions. These will of course be dependent on the degree of tilt, its orientation and the latitude of the place where the measurements are to be made. To obviate the ambiguities involved in making measurements in tilt position, Fröhlich recommends measurements on horizontal surfaces and then conversion of these measurements to the required plane theoretically. But, however good they may be, these computations will involve some theoretical models and some assumptions on the isotropy of the reflected radiation and of the scattered (diffuse) radiation. Hence a practical study on the effect of tilt on pyranometer is more desirable.

2. Instrumentation

The major factors which cause variation in the sensitivity of a pyranometer used at a tilted position may be due to the following :

(a) Changes in convection losses of the surface of the thermopile to its surroundings, mainly the hemispherical glass dome.

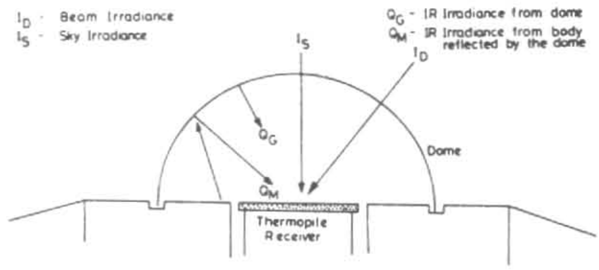

Fig. 1. Schematic diagram of energy on a pyranometer's receiver (Zerlaut and Maybee 1984)

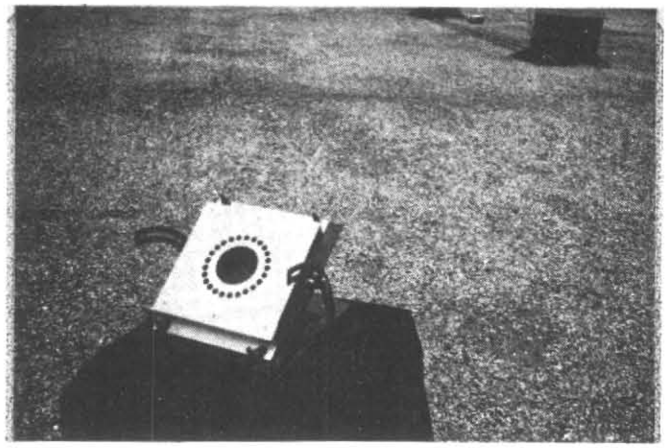

Fig. 2. The inclined plane table

(b) The infrared (IR) exchange between the receiver and the sky and the ground is different at different tilt angle.

(c) The anisotropic reflectivity from the under surface, *i.e*, the anisotropic nature of the albedo of the surface which the sensor will look at in the tilted position.

(d) The anisotropic scattered sky irradiance.

(e) The warming by direct irradiance of the pyranometer body while in installation. Even it is covered in the sides, the air inside is heated unevenly in different directions.

Dehne (1984) strongly recommends the use of artificial ventilation of the pyranometer domes to reduce errors due to the infrared (IR) contribution. He is of the opinion that forced ventilation reduces the effect of IR irradiance by a factor of 5. Fig. 1 (Zerlaut and Maybee 1984) gives some idea of the various factors that affect the energy exchanges at the thermopile.

The set up used is an adjustable inclined plane alongwith an optic bench set up. Two steel plates of size 270 mm × 245 mm × 3 mm are joined at one end by hinges (Fig. 2). Two graduated curved arms serve as the support for the plate whose inclined angle is to be adjusted. The other plate has two rails welded to it so that it snugly rests on the rails of an optic bench. A spirit level mounted on the horizontal plate enables proper levelling. A conventional aluminium mount used for outdoor installation of pyranometers is fixed to the inclined plate so that a pyranometer can easily be mounted on it.

The optic bench used is the one which is used for determining the cosine error of the pyranometers (Kanade 1992). The optic bench arrangement has basically two metallic rods bent into semicircular arcs and mounted on steel balls at both ends. The two arcs are graduated in degrees and have provision for carrying a lamp holder which carries a 200 W tungsten halogen lamp and an achromatic lens. The lamp is positioned

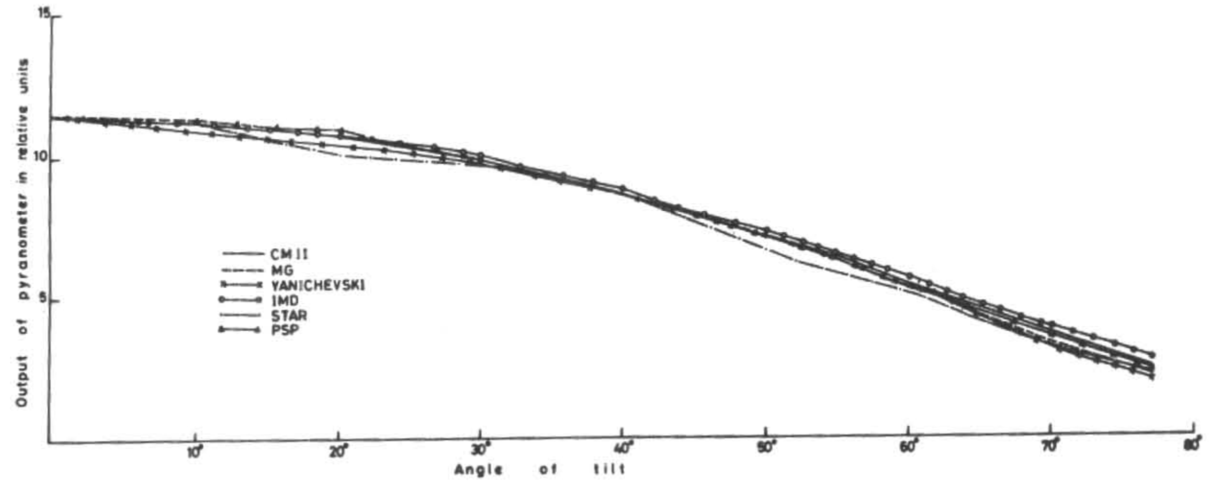

Fig. 3. Variation of output with angle of tilt

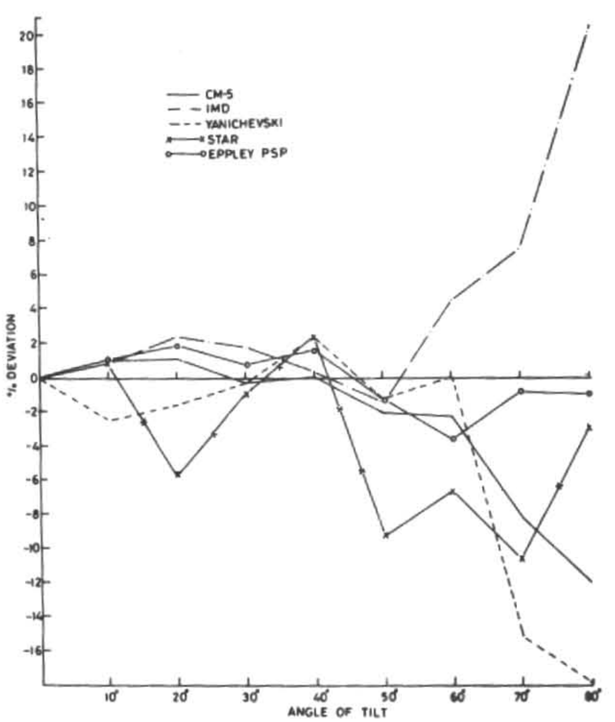

Fig. 4. Performances of pyranometers with reference to CM-11 at corresponding tilt angles

at the focal point of the lens so that an achromatic and well-collimated beam can illuminate and heat the thermopile sensor.

In the measurements to study the tilt effect, the lamp is mounted at the zenith point, *i.e.*, at 90° marking on the arc so that the irradiation will be perpendicular to the pyranometer when the tilt attachment is kept at 0° tilt, *i.e.*, in exactly horizontal position. The adjustable plate carrying the pyranometer is, then, positioned for different tilt angles from 0° through 80°.

(a) The irradiance is kept fixed at 200 Wm^{-2} with the lamp fixed permanently at the zenith position on the arc. The current supply is from a stabilized D.C. supply maintained at 24V 8A D.C. as recommended for the lamp.

(b) The output of the lamp is checked every time the reading is taken by a well calibrated Eppley thermopile which is always held perpendicular to the irradiation.

(c) After the tilt angle is changed and set at a new angle, sufficient time is allowed for the equilibrium condition to be achieved. The steadiness of the output from the pyranometer is also an indicator.

(d) To ensure that there is no stray reflection on to the pyranometer, the entire area is provided with matt black surroundings - including the ceilings. The table top is made of matt black perforated sheet so that the reflection from it is nearly absent.

(e) All objects including power supply, read out units and even the observer are all stationed on the opposite side of the direction of inclination and at a level lower than the table on which the optic bench is mounted.

3. Pyranometers under test

As many as six different pyranometers have been subjected to this tilt effect. They are,

(*i*) CM-11 pyranometer (Kipp & Zonen)

(*ii*) CM-5 (MG Type) pyranometer (Kipp & Zonen)

(*iii*) PSP pyranometer (Eppley)

(*iv*) Star pyranometer (Philip Schenk)

(*v*) Yanichevski pyranometer (Russian)

(*vi*) Thermopile pyranometer (Indian)

Each of the pyranometers was mounted on the optic bench and subjected to tilt angles of every 10° from 0° through 80°.

4. Comparative study of the performance of different pyranometers

The output of each pyranometer for each tilt angle was measured on well-calibrated HIL 4 1/2 digit millivoltmeter. In each case, the stability of the lamp output was checked using a calibrated Eppley thermopile held at normal incidence. These outputs were, then, normalised with that of the output at 0° angle of incidence for respective pyranometer. Fig. 3 gives the normalised output of various instruments in relative units for different angles of incidence.

The immediate feature that draws attention is the narrow width of the scatter of outputs of different pyranometers for a given and steady 200 Wm^{-2} irradiance, Yanichevski and the star pyranometers show a lower output at 20° tilt as against the nearly steady performance of the other pyranometers. This problem with the lower output repeats for the star pyranometer for tilt angles between 40° and 70°. Between 30° and 40° tilts, the relative outputs of each instrument is nearly the same as any other pyranometer. Beyond 50° tilt, there is a slight increasing flaring towards 80° in the outputs. The extreme case of 90° tilt was not considered because of the likely large errors in the very low output of each pyranometer. It is also seen that the IMD pyranometer shows a lower variation at higher tilt angles.

CM-11 pyranometers, Kipp and Zonen say, do not exhibit any tilt effect. Even the calibration certificate indicates that there is no tilt effect. Many research scientists like (Dehne 1984) and (Nast 1983) found that CM-11 does not have any tilt effect. Fig. 4 gives the comparative performance of other pyranometers with reference to CM-11. The PSP pyranometer which in general is reported to have no tilt effect, showed least deviations from the CM-11 values and they were well within 2 percent, except at 60° tilt when it is 3.5 percent. Almost all the pyranometers excepting the star pyranometer have less than 2 percent departure up to a tilt angle of 60°. Beyond 60°, all instruments excepting PSP show larger deviation with respect to CM-11. Excepting the IMD pyranometers, all others show negative deviation. CM-5 pyranometer has 11 percent negative departure at 80° tilt angle. Yanichevsky pyranometer which was showing very low departure up to 60°, suddenly shows 15-18 per cent variation beyond 60°. Star pyranometer showed uneven fluctuations of the order 8 per cent even at 50° tilt. Liedquist (1984) found that the black and white instruments have different tilt effects for different orientations. The IMD pyranometer, on the other hand, shows a very large deviation of the order of 20 per cent. The cosine error measurements also showed large error at 80° zenith angle. It was found that the surface was having very sharp sloping at the edges and hence the output of the pyranometer suddenly showed an increase.

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