Paper No. 68

A VERSATILE INSTRUMENT FOR THERMAL RADIATION MEASUREMENT

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ABSTRACT

A radiometer has been designed, fabricated, and tested which is rugged, versatile, and highly reliable for measurement of real or simulated solar radiation in an ambient or vacuum environment, and for measurement of total hemispherical infrared radiation in a vacuum. This radiometer may be considered as an all purpose radiometer for space environment simulation and testing.

INTRODUCTION

There are a number of types of radiometers used in solar simulation that employ a variety of sensing principles. Photoelectric, photoemmissive, and photoconductive instruments have an extremely fast response time and are very sensitive; however, they are spectrally selective. Thermal devices such as thermopiles and bolometers have a relatively slow response time (one second time constant or greater), are very delicate, and are of low sensitivity (5 to 15 millivolts per solar constant). Also, thermal devices are spectrally nonselective, which permits them to be used in solar simulation measurements and the uncertainties caused by spectral nonuniformity may be eliminated. Where spectral uniformity is assured, photon-activated devices, generally solar cells, are used. Another advantage of photon-activated devices is that their sensitivity does not vary with atmospheric pressure (from vacuum to one atmosphere), and they do not respond to thermal radiation (when selected for response in the solar spectral range). An additional problem with photon-activated sensors is that they must be calibrated against a standard whose spectrum is the same as that to be measured.

The closest device to qualifying as a hybrid of the photon and thermal sensors is the thermodielectric sensor. In this sensor a slight change in temperature of a black surface absorbing light causes a change in dielectric constant, which is detected when the sensor is in a capacitance bridge circuit. This type sensor is sensitive, spectrally nonselective and quite fast in response time.

However, it is delicate and temperature sensitive and has not been used (to the author's knowledge) in solar simulation measurement. One of the manufacturers does not recommend it for use in solar simulation measurement.

Space environment simulation has the additional requirement of nonselective measurement of infrared radiation (3 to 100 microns wavelength) that is incident from any variety of geometries within a hemisphere of view as well as measurement of solar and/or infrared energey absorbed by a given surface material (e.g., thermal control coating).

A thermal-type sensor has been designed, fabricated, developed, and tested. This sensor is more sensitive and faster to respond than most other thermal sensors and can be used for measuring infrared and absorbed irradiance, and incident solar irradiance.

DESCRIPTION

The instrument consists of two semicircular Boelter-Schmidt type sensors mounted adjacent to each other on a cylindrical aluminum block (fig. 1). The sensors are painted with a black matte finish, and two output leads from each sensor extended from the block. A thermocouple is mounted in the block along its center line and near the face of the sensors. The instrument can be mounted on a cylindrical heater Bezel (fig. 2) of the same diameter as the radiometer. The heater Bezel contains two independent thermostated heaters that control at approximately 90° ± 5° F. Two sets of 110-volt leads come from the heater Bezel, which weighs about 3 ounces.

The Boelter-Schmidt type sensors were selected for this radiometer because they are very rugged and measure heat transfer, regardless of mode (absorbed, emitted, conduction, convection). The versatility of the radiometer is due to its configuration and the data reduction technique used to determine the heat transferred into the sensor by each mode, or a selected combination of modes. The sensors may be considered as elements in a thermal circuit in which heat flow is measured by the temperature differential across them, just as current flow is measured by the voltage differential across a low-value resistor.

IRRADIANCE MEASUREMENTS IN THE SOLAR SPECTRAL RANGE

For measuring irradiance only in the solar spectral range (0.2 to 3.5 microns wavelength), the radiometer is outfitted with a half-silvered quartz window (fig. 3) that is similar to the window used in a split disc bolometer commonly used in solar simulation practice. The window is circular, one-half is clear with the other half bearing a vacuum deposited aluminum coating. The window is mounted on the radiometer so that the aluminum is used as a second surface reflector. The aluminum is coated over with black matte paint, so both sensors view a surface or high emittance (the quartz is also very high emittance). In this configuration, the sensor covered with the second surface mirror receives radiation only from the quartz, whereas the sensor viewing through the clear quartz receives transmitted radiation as well as that emitted by the quartz. If the negative electrical outputs of the two radiometers are tied together, and the positive output of the mirrored sensor is connected to the negative terminal of a millivoltmeter, and the positive lead of the unmirrored sensor to the positive terminal, the radiometer will measure the net transmitted radiation through the window only, being a single compensated radiometer. A stand-off ring must be employed to keep the quartz window from contacting the sensor surfaces. A ventilation hole must be provided for gas pressure between the window and the sensor to be the same as that of the environment. The window mounting device must be designed so that pressure on the radiometer body is avoided (as applied with a set screw). A slight distortion of the body may cause a sensor to detach from the body. Finally, the window must be very carefully alined over the sensors so that the mirror edge is exactly over the line separating the two semicircular sensors.

MEASUREMENT OF TOTAL INCIDENT IRRADIANCE

Total solar and infrared incident irradiance can be measured by either sensor when no window is employed. The signal received is proportional to the net heat transferred through the sensor. To determine the incident irradiance on the sensor the quantity σT_R^4 must be added to the net transfer value (T_R = radiometer temperature, σ = Stefan-Boltzmann constant). An emissive value is not necessary because assuming the black matte coating is a "gray" surface, absorptivity is the same as emissivity. If the radiometer is calibrated for incident irradiance, no adjustment in the amount of calculated emitted irradiance is necessary.

MEASUREMENT OF NET ENERGY TRANSFERRED THROUGH A SURFACE

If the radiometer is coated with a particular gray or nongray material and is employed without a window, the signal generated by the radiometer is proportional to the net heat transferred through that surface at the temperature of the radiometer. The sensitivity factor (calibration) of the radiometer in heat per unit area per unit time per millivolt is adjusted by dividing that value by the hemispherical emittance of the black matte coating on the radiometer present when the radiometer was calibrated. The best method of calibrating the windowless radiometer is to place it in a vacuum chamber outfitted with a black matte liquid nitrogen cooled shroud. The radiometer should be mounted on an aluminum or copper block having water or water-glycol solution flowing through at a minimum rate of 0.2 gallons per minute. The water temperature should be controlled by a suitable circulating bath. The output of the radiometer when viewing the cold environment at a pressure of less than 10^{-5} torr is proportional to the heat emitted to the environment, less a small amount of heat received. The sensor sensitivity can be determined according to the following equation:

$$\text{millivolts output (mv)} = \frac{\sigma T_r^4 - \sigma T_w^4}{S}$$

where σ = Stefan-Boltzmann constant, 0.173 x 10 btu/ft - hr °R

S = radiometer sensitivity for incident radiation

T_w = shroud (wall) temperature - °R

T_r = radiometer temperature - °R

This calibration is a single point absolute calibration for hemispherical infrared radiation viewed in a vacuum. To covert the calibration to net heat transferred through the radiometer, the value S is divided by the hemispherical emittance of the black matte surface, which is approximately 0.89.

MEASUREMENT OF SOLAR ABSORPTANCE AND EMITTANCE OF AN UNKNOWN SURFACE

If a sufficiently thin (0.005-inch or less) layer of a surface coating is applied on one sensor surface and the other sensor left black, the emittance can be determined as follows:

$$\text{Emittance } [\epsilon] = \frac{\text{mv. coated sensor}}{\text{mv. black sensor}} \times \frac{\text{sen. coated sensor}}{\text{sen. black sensor}}$$

$$\times \text{ emittance of black surface}$$

If the windowless radiometer, in a vacuum chamber at less than 10^{-5} torr atmosphere views radiation from a solar simulator of good spectral quality, the solar absorptance of the unknown surface is determined as follows:

$$\text{Absorptance } [\alpha] = \frac{\text{mv. coated sensor}}{\text{mv. black sensor}} \times \frac{\text{sen. coated sensor}}{\text{sen. black sensor}}$$

$$\times \text{ solar absorptance of black surface}$$

CHARACTERISTICS AND PERFORMANCE

The physical and performance characteristics of the radiometer are as follows:

Diameter	1.5 inches
Depth	1.0 inches
Weight with window (without heater)	100 grams
Coating on sensors	3M Nextel 410C black
Range	0 to 3 solar constants
Sensitivity, with window	26 millivolts/solar constant
Time constant of response	0.5 seconds
Sensitivity air/ sensitivity vacuum	0.98
Drift in signal at one solar constant, windowed configuration, temperature range -50 °F to +92 °F	1.0 percent
Linearity	±1/2 percent within 0-3 solar constant range
Operating temperature range	-50 to 150 °F
Drift in signal, radiometer at room temperature exposed to one solar constant, from 30 seconds after initial exposure to 2 hours later	0.3 percent

The light weight of the radiometer and ability to include all necessary controls and output information in a small single unit with a 10-wire cable make it very amenable for use in remote and fragile configurations. The high sensitivity and fast response permit its use in scanning systems. Since the ratio of sensitivity in air to that in vacuum is close to unity, only a single initial determination of this ratio is required for the radiometer. Other radiometers used in space environment testing have sensitivity ratios that are considerably less than unity and must be frequently checked for variation in that ratio. The low signal drift is due to the compensated configuration, which eliminates the signal due to window heating. Window heating of noncompensated solar measuring radiometers give errors of approximately 8 to 10 percent as the windows slowly heat on solar exposure to an equilibrium temperature.

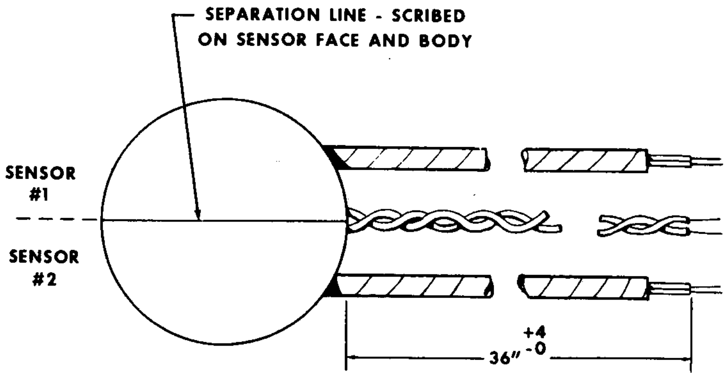

Fig. 1 - Basic two sensor instrument

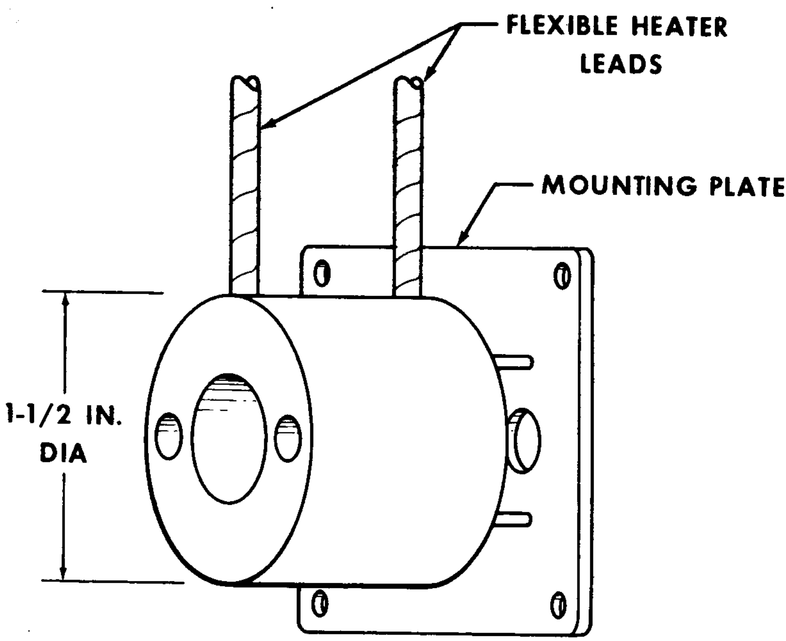

Fig. 2 - Heater Bezel

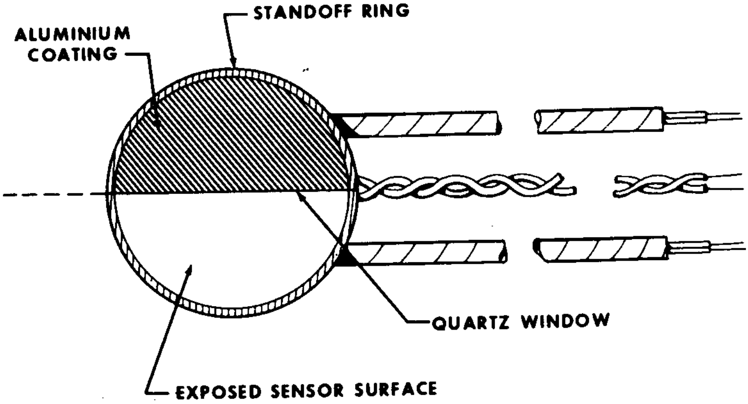

Fig. 3 - Configuration for solar measurement