Geof. Int., Vol. 28-1, 1989, pp. 89-101

FAST RESPONSE THERMOPILES

J. MARTINEZ-GUERRERO*
L. F. DEL CASTILLO**
(Received: May 20, 1988)
(Accepted: September 19, 1988)

RESUMEN

Desde la introducción del transductor en la medición de la radiación solar por Crova en 1890, dos rasgos, la sensitividad y el tiempo característico representan parámetros constantes de una termopila. En este trabajo se describe un instrumento con sensitividad continuamente variante y tiempo constante (TC), capaz de alta resolución en tiempo, en los alrededores de 25 milisegundos. Se demuestra también que, si la sensitividad y el TC son variantes, se encuentran relacionados matemáticamente en una relación lineal simple.

ABSTRACT

Since the introduction of the thermoelectric transductor in the measurement of solar radiation by Crova in 1890, two features, the sensitivity and characteristic time, represent constant parameters of a thermopile.In this paper, an instrument is described with continuously varying sensitivity and time constant (TC), capable of high resolution in time, in the environs of 25 milliseconds. It is also demonstrated that, if the sensitivity and TC are varying, they are mathematically related in a simple linear relationship.

* *Instituto de Geofísica, U.N.A.M., MEXICO, D.F.*

** *Instituto de Investigaciones en Materiales, U.N.A.M., MEXICO, D. F.*

INTRODUCTION

Crova in 1890 made a revolutionary advance in the field of the solar radiation measurements, with the introduction of a thermoelectric sensor in a pyranometer (Gorczyñski, 1928). Also Möll and Gorczyñski (1924) and Kimball and Marvin (1925) developed similar instrumental methods using thermopiles.

Since then, sensitivity and time constant were considered within certain limits as invariants, typified for each individual pyranometer.

On the other hand, during the most part of the present century, the peculiar slow response of the dispositive did not affect notably the measurements of the solar radiation due to the high atmospheric transparency, then the slower thermopiles assured good results. As it is very well known, that condition has changed radically, with the result that it is no longer acceptable to use transductors that do not follow with fidelity the fast changes of the radiation intensity, propitiated by the present atmospheric conditions. Figure 1 shows the signals registered by two thermopiles of different time constant of a radiation coming from an alternating source. The difference between both readings is noteworthy.

The purpose of this work is to indicate the general design characteristics to achieve fast response thermopiles. Following the norms that a pyranometer must fulfill as defined by the World Meteorological Organization, the authors constructed the instrument shown in Figure 2. The principal characteristic of this pyranometer is the variability of its sensitivity and the time constant, which is produced by changes of the air volume in a cavity under the thermopile.

The analysis of this instrument, its operation and a formal description of its variable cavity will be presented in what follows.

DESCRIPTION OF THE PYRANOMETER

As seen in Figure 3, inside the glass cover, a thermopile of radial configuration is mounted on a mica substrate and nested as a lid closing the top of a cylindrical cavity, in such a way that the reference junctions are in coincidence with the lip of the cavity, to establish properly the heat interchange between the hot junctions of the thermopile and the thermal sink, that comprises the metallic frame of the apparatus.

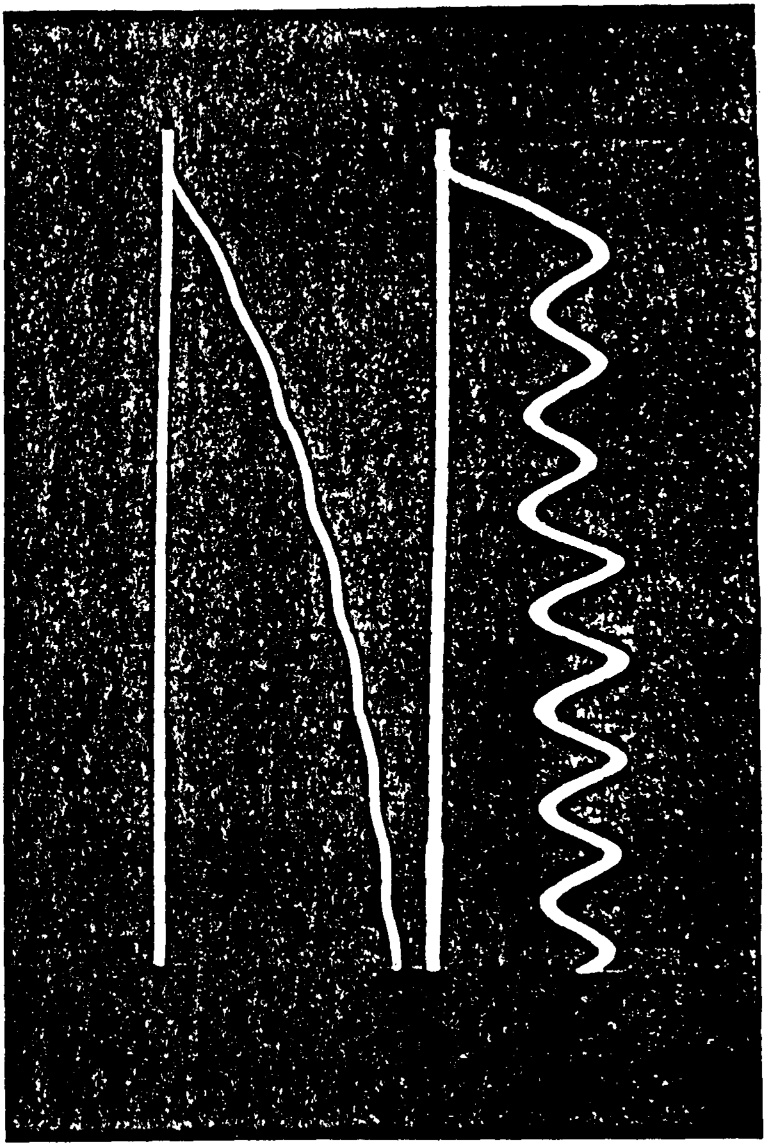

Fig. 1. Comparison with a fast response pyranometer.

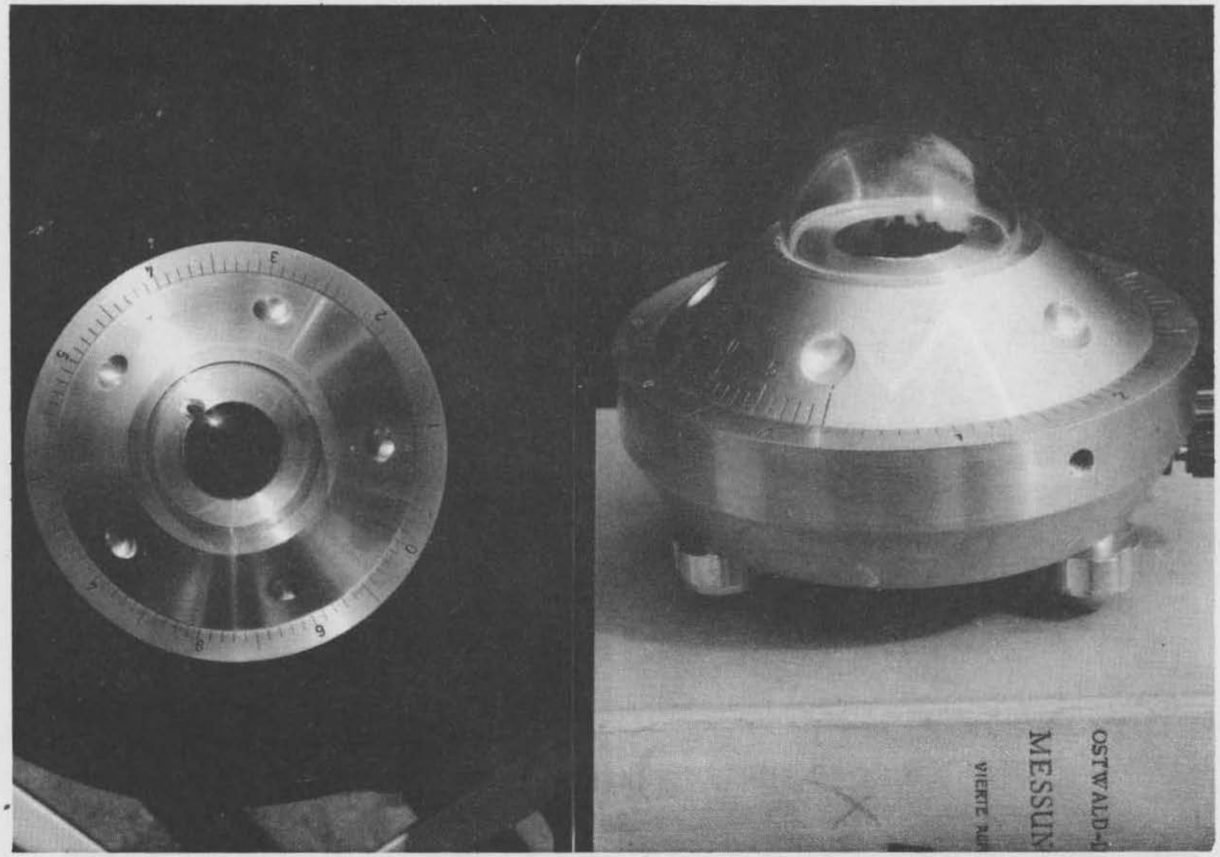

Fig. 2. Photograph of a pyranometer with sensitivity and time constant capable of being continuously varied.

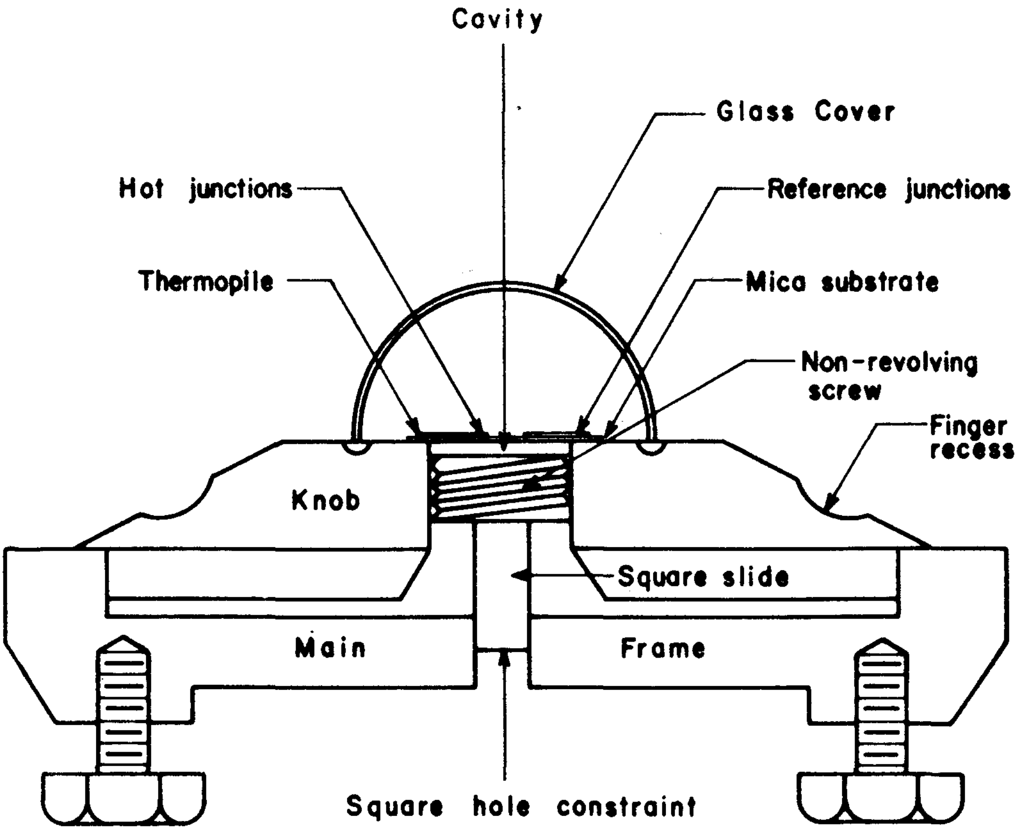

Fig. 3. Diagram of the pyranometer.

The cavity is closed in the bottom by means of a flat screwed piston. Its air volume can be varied when a torque is applied with the fingers to the spherical recesses of the conical knob, which is free to turn with respect to the main frame of the device. On the other hand, the piston is not allowed to rotate due to a constriction exerted by an extension of the screw, which fits tightly into a square section hole made in the lower frame, that checks the rotational movements but allows only the axial displacement. Thus the distance between the thermopile plane and the piston is accurately measured and reproduced by means of a circular scale engraved in the visible periphery of the instrument.

EXPERIMENTAL DETAILS

When the instrument is in operation under the irradiation of a constant intensity source, it is possible to change the sensitivity and the time constant of the thermopile simultaneously. Figure 4 shows the graph of the sensitivity variance when the distance between the piston and the thermopile is changed. This capability is certainly convenient when several instruments are under simultaneous operation, because it allows to equalize the sensitivity of all instruments or to adjust them to certain preferred values to simplify the processing of information.

Figure 5 shows the change of dynamical response with a variation of the distance. This characteristic permits performing measurements of fast changes in the intensity of radiant energy. Finally, the graph of Figure 6 shows the relationship between sensitivity and the time constant.

INTERPRETATION OF THE EXPERIMENT

The formal description of the effect of a cavity of variable height under the thermopile can be done, using the heat conservation equation in cylindrical coordinates with appropriate boundary and initial conditions. However, this formal analysis will be avoided in order to present a simplified mathematical explanation of the phenomenon described in this paper. In fact, as a simplification to obtain a response function of the thermopile closing the cavity, the heat balance is applied to the cavity of constant height. In such conditions the Fourier law can be written as a finite-difference in order to compute the transmitted heat from the thermopile to the cavity. Later on, the treatment is generalized to any arbitrary height of the piston. The variation in the thermal gradient is introduced by using a factor that approaches the z variable when $z \to 0$, to let the Fourier law in the form of finite-difference as a limiting case for small height, that is:

$$\frac{d\,T(z)}{dz} = -\frac{T(z) - T_0}{\frac{kA}{g}\left(1 - \exp - \frac{g}{kA} z\right)} \qquad (1)$$

where T_0 is the temperature of the piston and $T(z)$ is the temperature of the thermopile when the piston has been displaced to any arbitrary position (z); k is the thermal conductivity of the air; A is the surface area of the thermopile and g is a proportionality constant to introduce consistency between the energy exchange in the cavity and the thermopile with the temperature variation when the piston position changes.

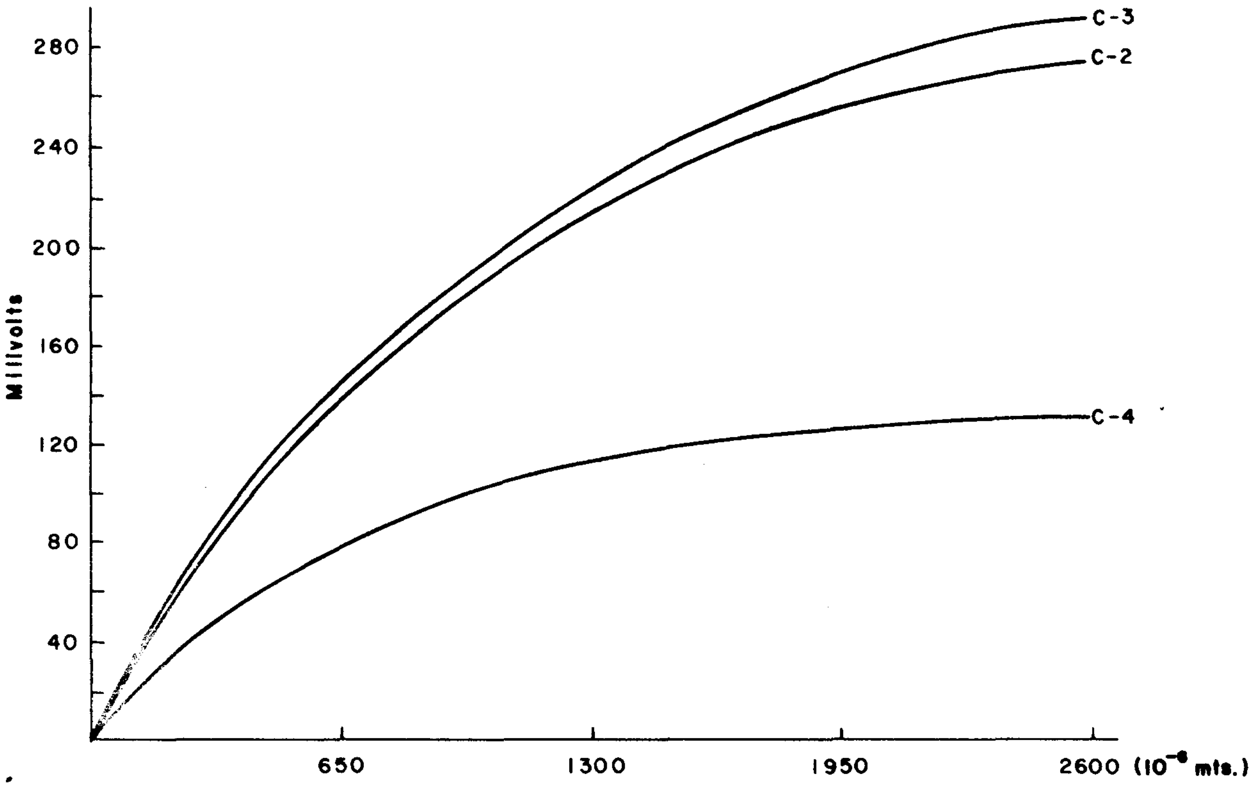

Fig. 4. Sensitivity vs. piston position from the top under a constant level of radiation (1.917 Langley/min.).

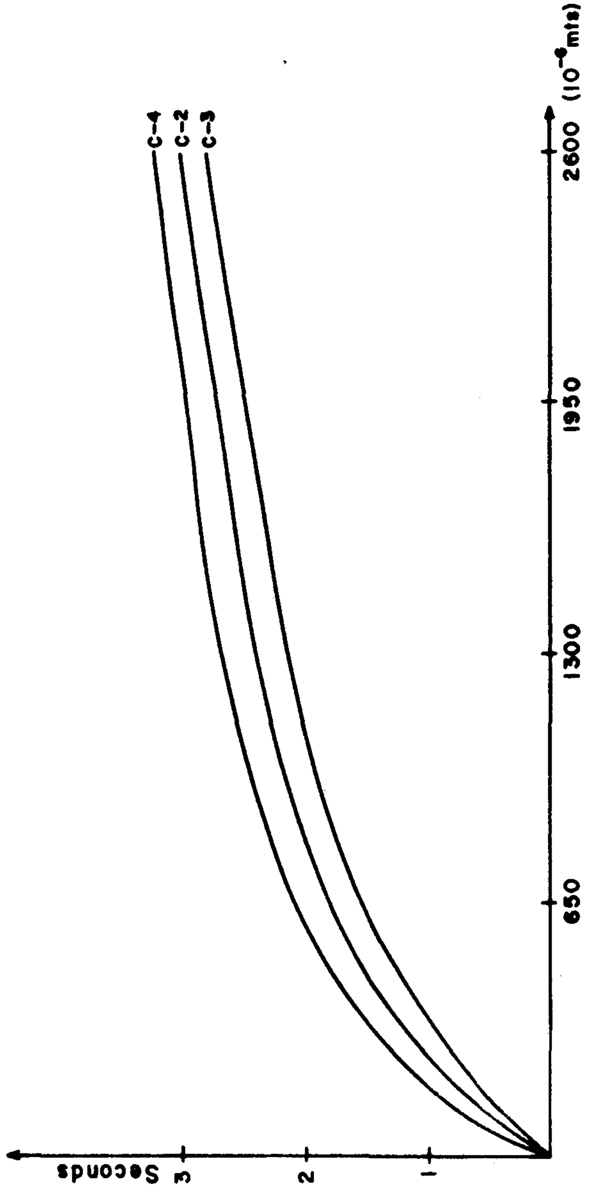

Fig. 5. Variation of time constant in terms of piston position from the top.

The time dependency appears by invoking the energy balance of the thermopile, *i.e.*

$$-JA + J_t A = -c \frac{\partial T(z)}{\partial t} \qquad (2)$$

where c is the thermal capacity of the thermopile at constant volume, J is the effective energy absorbed by the thermopile per unitary area and time, and J_t is the transmitted energy to the cavity from the thermopile, which may be evaluated by using equation (1) according to the following expression

$$J_t = -k \frac{dT(z)}{dz} = \frac{T(z) - T_0}{\frac{A}{g}(1 - \exp - \frac{g}{kA} z)} \qquad (3)$$

Assuming that J and the other parameters are independent on the time, it is possible to integrate equation (2) using equation (3) and applying the condition $T = T_0$ if $t = 0$.

The solution $T = T(z, t)$ is

$$T = T^0 + \frac{JA}{g}(1 - \exp - \frac{g}{kA} z)(1 - \exp - \frac{t}{\tau}) \qquad (4)$$

where

$$\tau = \frac{c}{g}(1 - \exp - \frac{g}{kA} z) \qquad (5)$$

Equation (4) describes the experimental result observed in Figures 4, 5 and 6. In fact, the sensitivity of the pyranometer is directly proportional to the difference $\Delta T = T - T_0$, and experimentally depends on time. The stationary state is obtained when $t \to \infty$ where ΔT is only a function of z:

$$\Delta T = \frac{JA}{g}(1 - \exp - \frac{g}{kA} z) \qquad (6)$$

Equation (6) describes the tendency shown in Figure 4, since according to equation (6) it is an exponential expression with an asymptotic value proportional to JA/g.

On the other hand, the TC is given by equation (5), which again is an exponential function of z with an asymptotic value given by c/g, as it is seen in Figure 5.

As it is evident, the sensitivity in a steady state condition and the TC are proportional. In fact, using equations (5) and (6) it follows that

$$\Delta T = \frac{JA}{c} \tau \tag{7}$$

Figure 6 illustrates this linear dependence in three different thermopiles, except when the piston is touching the thermopile, when there is no longer any air inside. Then the mica sustract acts as a second cavity that follows all the peculiarities of a real cavity. Whenever the thickness of the mica diminished, the time constant and the sensitivity also diminished. In this way, it was possible to obtain very fast response thermopiles.

The influence of the mica substrate was avoided when the thermopiles were mounted directly on the thermal sink electrically insulated by means of an interferometrical film of alumina. In this way time constants in the environs of 25 milliseconds were reached. Therefore, it is possible to establish that the observed phenomenon depends basically on the volume enclosed in the cavity.

Finally, the results given by equations (4), (5) and (6) have been obtained by the introduction of a new constant g, that can be evaluated by means of equation (5) for a distant position of the piston. In such case

$$g = c/\tau_m$$

and in this way, it is possible to obtain a quantitative description of the phenomenon. However, the proportionality coefficient between the temperature difference in the thermopile and the generated emf is necessary.

DISCUSSION

A pyranometer with continuously varying sensitivity and time constant was described. In this pyranometer, the sensitivity can be adjusted and matched to the lecture of another instrument. Its design principle is based on a variable cylindrical cavity underlaying the thermopile.

Furthermore, it was shown that the time response of a pyranometer is a consequence of the thermopile mounting. For fast response, it is necessary to avoid as much as possible the cavity underlaying the thermopile.

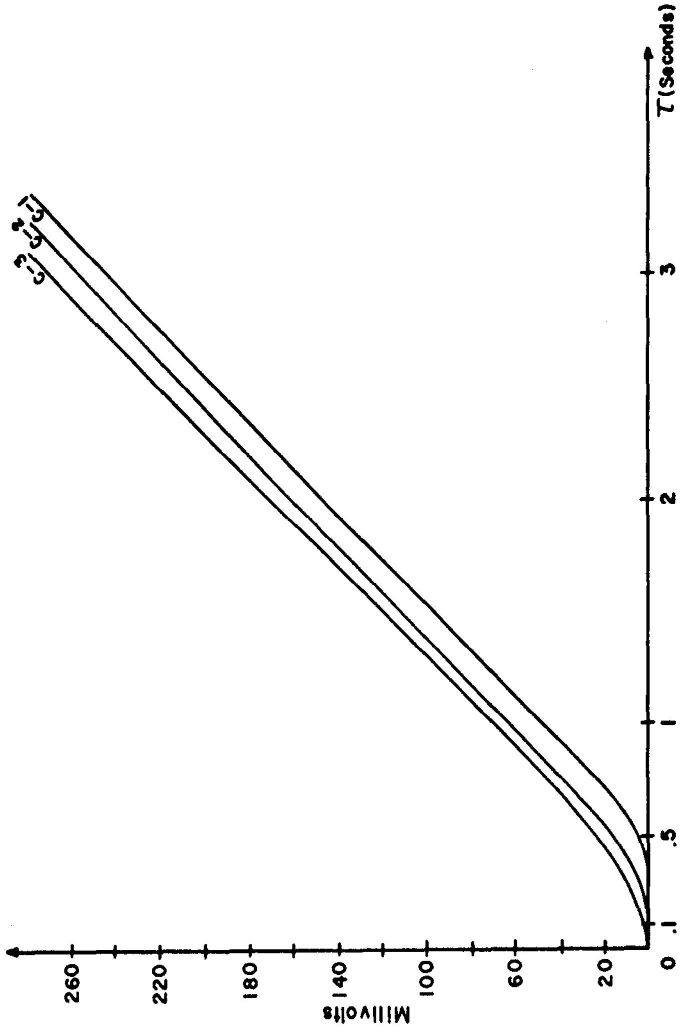

Fig. 6. Sensitivity vd. time constant.

Finally, it should be remarked that, in order to make possible the experimental observation for fast response, a very thin thermopile with high sensitivity has been developed. Using this special thermopile, it was possible to get a pyranometer with a time constant in the environs of 25 milliseconds and a sensitivity around 12 millivolt/Langley/minute.

ACKNOWLEDGEMENTS

One of the authors (L.F. del C.) wishes to acknowledge long discussions on many different occasions with Dr. U. Oseguera concerning formal description. We also thank Dr. E. Ramos for helping us with experimental facilities.

NOMENCLATURE

A	area of the thermopile
c	thermal capacity of the thermopile
g	proportional constant
	$= c\,\tau_m - 1$
k	thermal conductivity of the air
J	effective absorbed energy
J_t	total transmitted heat
t	time
TC	time constant
T(z)	temperature of the thermopile when the piston is at z position
T(z, t)	general solution
T_0	temperature of the piston
z	height of the piston

Greek letters

τ	time constant
τ_m	maximum time constant

Subscripts

m	maximum
o	constant value
t	total

BIBLIOGRAPHY

GORCZYŃSKI, L., 1928. Actinómetros termoeléctricos para las medidas totales, normales y espectrales de la radiación solar. Folleto # 1. Radiación Solar. Servicio Meteorológico Mexicano. Observatorio Central, Secretaría de Agricultura y Fomento. Tacubaya, D. F.

MARTINEZ-GUERRERO, J., 1981. Pyranometer with adjustable time constant and sensitivity. Second WMO Technical Conference on Instruments and Methods of Observation (TECIMO II), México 13 - 17 October. Memorias, pp. 271-274.

ROBINSON, N., 1966. Solar Radiation. Elsevier Co., New York.