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A. L. ALEKSANDROV

INSTRUMENT FOR MEASURING THE GEOTHERMAL GRADIENTS THROUGH THE OCEAN FLOOR*

The present period of geothermal research is characterized by the transition to investigations of inhomogeneities in the thermal field and to determinations of a relation between the inhomogeneities and the conclusions drawn from other geophysical and geological investigations. Measurements of the heat flux are difficult on the continents, because boreholes must be drilled and shafts must be sunk, which considerably disturbs the natural temperature field of the Earth and its crust. The heat flux is influenced by numerous factors which are hard to bring into account. These difficulties are not encountered in oceanological observations which are further characterized by the advantage that they can be made along selected profiles and that they can be combined with topographical work, and with seismic and magnetic profiling, in a much simpler way than observations made on the continents.

The present article describes the recording PTG-3 instrument designed for oceanological measurements of the geothermal flux. When the thermal gradient meter PTG-3 was developed [1], the experience gathered in the operation of our previously developed PTG [2] and PTN-1 [3] instruments was included in the design work.

Measurement method. The geothermal flux is measured with the PTG-3 instrument according to the usual method in which the temperature gradient and the thermal conductivity of sediments are separately measured; the thermal flux is then determined from the formula:

$$q = \lambda \nabla T, \tag{1}$$

where ∇T denotes the temperature gradient and λ the thermal conductivity of the ocean-floor sediments.

When the instrument is lowered, the probe is driven into the soft layer of bottom sediments by the force of the fall. The sensors, which are mounted at the lower and upper ends of the probe, measure the temperature difference. Knowledge of the temperature difference can be used to determine the vertical temperature gradient in the sediments from the expression:

$$\nabla T = \frac{T_u - T_l}{l \cos \alpha},$$

where T_u and T_l denote the temperature of the upper and the lower sensor, respectively; l denotes the distance between the sensors; and α denotes the angle between the direction in which the probe was inserted and the vertical.

The thermal conductivity of the ocean-floor sediments must be measured in the laboratory. To do this, samples of the sediments are lifted with the aid of a bottom tube attached to the probe of the instrument. The accuracy with which the thermal conductivity is measured, depends upon the methods selected and amounts to 3-10% [3].

The error which can be made in the measurement of the vertical temperature gradient, depends upon the angle under which the probe entered into the sediments and upon the errors with which the temperatures and temperature differences were measured. Repeated tests have shown that the hydrodynamic features of the PTG-3 instrument, which is attached to a cable with the diameter of 3 mm, guarantee that the probe enters practically in vertical direction into the sediments. The error was determined from the deviation of the temperature difference from the average value obtained on the ocean floor at several points spaced 100-500 m. The measured values were recorded on the surface with the aid of accurate telemetric equipment. The error determined in this fashion was usually less than 3-5%. Exceptions were cases in which the probe did not enter at all into the sediments so that the instrument was lying on the ocean bottom. This occurred on very compact sediments.

An accuracy of the order of 0.005°C could be obtained in the measurements of temperature differences with the PTG instruments. However, this accuracy could be reached only when thermistors with identical parameters were selected for the temperature sensors. When the parameters of the thermistors differ, the equilibrium of the bridge is disturbed not only by changes in the temperature of one of the sensors but also by changes in the temperature of both sensors. For a small temperature interval, the dependence of the thermistor resistance R_T upon the absolute temperature T is given by the formula:

$$R_T = A e^{B/T}. \tag{2}$$

where A and B denote characteristic thermistor constants. It can be shown that bridge equilibrium is obtained under the condition (Fig. 1):

$$R_1/R_2 = \frac{1}{1 + A_1/A_2 e^{B_1/T_1 - B_2/T_2}}. \tag{3}$$

When the right hand side of this equation is expanded into a power series, we obtain:

$$R_1/R_2 = \frac{1}{1 + A_1/A_2}\left[1 - \frac{A_1/A_2}{1 + A_1/A_2}\frac{B_0}{T_0}\left(\frac{\Delta T}{T_0} - \frac{\Delta B}{B_0}\right) + \ldots\right]. \tag{4}$$

where B_0 and T_0 denote the average values of thermistor parameters B_1 and B_2 of similar magnitude and of temperatures T_1 and T_2, respectively. It follows from Equation (4) that temperature variations from 0 to +10°C, which occur during the measurements in the water surrounding the probe, can noticeably disturb the bridge equilibrium even when the parameter differences $B_1 - B_2 = \Delta B$ are very small. In practice, nonidentical thermistor parameters shift the line corresponding to the recording of the zero of the temperature difference. Therefore, when actual measurements were made, a preliminary recording of the zero-line was made before the recording of the geothermal gradient. To do this, the instrument is kept for some time in the water layer close to the ocean floor (20-50 m above the ocean floor), where the vertical gradient usually does not exceed $2\text{-}4 \times 10^{-4}$ degree/m. Then the probe is lowered into the bottom sediments. In order to determine the geothermal gradient, the stationary value of the temperature difference reckoned from the zero line is used. In order to compensate for shifts of the zero line, the recording range must be close to ±0.5°C; the accuracy of recordings, with which a measurement error of 5% can be reached at normal geothermal gradients, must be of the order of 0.2%. When the line of the recording trace has

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*Izv., Earth Physics, No. 3, 1975, pp. 99-103, translated by Joachim Büchner.

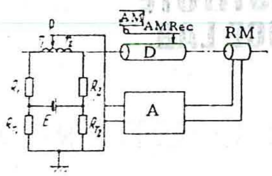

Fig. 1. Scheme of the PTG-3 instrument; R_{T_1} and R_{T_2} denote the resistances of the thermistors; they and R_1, R_2, r_1, and r_2 form a bridge for measuring the temperature differences. A - amplifier; RM - reversible motor; Rec - recorder; AM - feed mechanism of the recorder; P - slide-wire resistor; D - drum with graph paper.

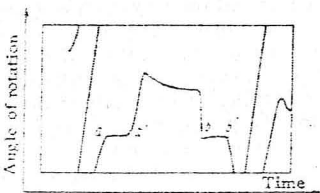

Fig. 2. Sample recording of the measurement of the geothermal gradient.

thickness of 0.2 mm, a chart with a width of 200-300 mm is required for obtaining this accuracy. In the recorder of the PTG-3 instrument, the chart is extended, because a multi-turn slide-wire resistor is used to balance the bridge.

Figure 1 shows the scheme of the PTG-3 instrument operation. The automatic regulator adjusts the drum to the position in which the bridge is balanced. The angle φ of drum rotation referring to the zero line, can be obtained from Equation (3), and is approximately equal to:

$$\varphi_{rad} \approx \frac{RB_0(T_u - T_1)}{2T_3^2 a\rho},$$

where a denotes the radius of the slide-wire resistor; and ρ denotes the resistivity per unit length of the wire from which the slide-wire resistor is made.

The sensitivity of the instrument depends upon the bridge resistances R and can be modified, if necessary.

The maximum angle of rotation is 1400° in the four-turn slide-wire resistor of the PTG-3 recorder. The temperature difference is recorded as a function of time. To this end, the recording device is slowly and continuously shifted parallel to the axis of the drum. The maximum rate of drum rotation and the rate of the gradual shift of the recording device are adapted so that the recording device must pass through a distance corresponding to several times the thickness of the recording line during a single drum rotation. When this ratio of advance rates is obeyed, it is easy to calculate on the diagram the number of drum revolutions effected before a departure from the zero line occurred on the recording; once the probe has been calibrated, the corresponding temperature can be determined.

Figure 2 is a sample recording obtained in the measurement of the geothermal temperature gradient on the

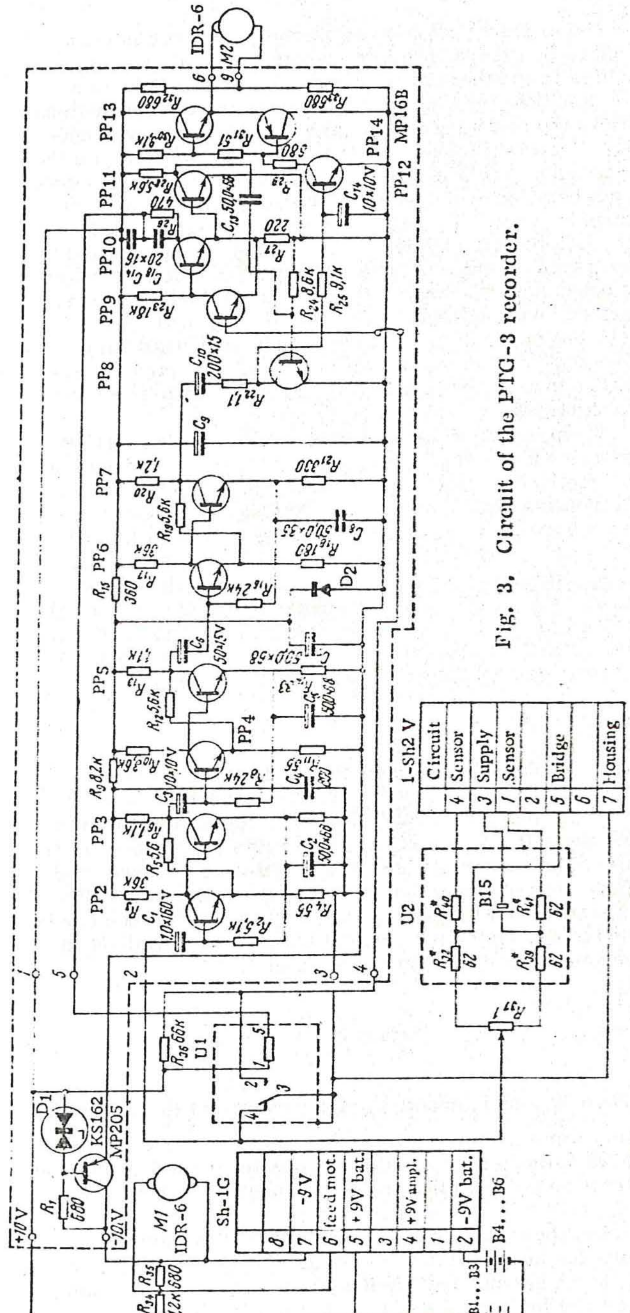

Fig. 3. Circuit of the PTG-3 recorder.

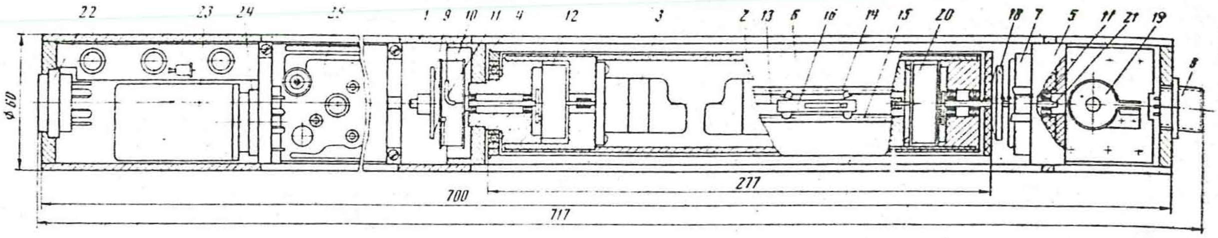

Fig. 4. Design of the recorder:

1) housing; 2-3) electric motors; 4) bearing; 5, 7, 17) slide-wire rheostat; 6) drum; 8) junction for the probe; 9, 18) friction sleeves; 10) drum of wire; 11) directionalizing wires; 12, 20) reduction gears; 13, 16) components of the recorder unit; 19) battery of bridge; 21) shaft; 22) supply junction; 23) vibrator; 24) printed circuit board of the amplifier.

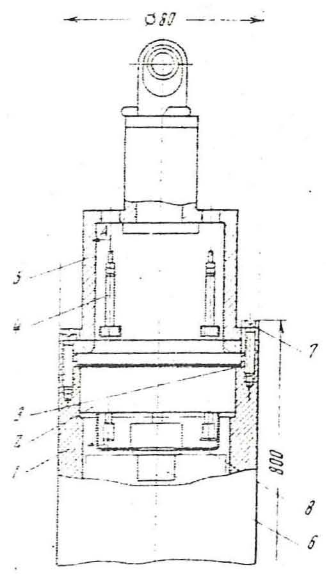

Fig. 5. Design of the container of the instrument:

1) housing; 2) lid; 3) rubber packing; 4) electrical inputs; 5) protective cover; 6) connector for recorder; 7) screws for attaching the flange; 8) sleeve.

chart of an instrument with a spiral slide-wire resistor. The ring, which is formed by the chart, was cut so that the process could be more easily inspected. The lines at the beginning and at the end of the diagram result from the drum rotation while the temperature of the surrounding water changed with depth. The sections aa' and bb' are the zero line. Section a'b is a typical recording of a geothermal gradient measurement made with the probe lowered into the ocean floor sediments.

The circuits of the instrument are shown in Fig. 3. A d.c.-a.c. conversion with the aid of a VPM-2 vibrator is effected in the amplifier. The a.c. required for the vibrator coils is generated with the third and fourth contacts of the vibrator. This generator principle makes it possible to use the mechanical resonance of the oscillations of the vibrator armature. The power required for the electromagnet of the vibrator is therefore substantially reduced. The initial push to set off the armature of the vibrator is obtained from the energy supplied by the charge of capacitor C12. Synchronous detection is obtained with a switch consisting of transistor PP8. The d.c. amplifier works on an IDR-6 slave motor which rotates the drum. The instrument receives its power from a battery consisting of 8 D-O, 2 storage batteries or FBS-0.25 cells.

Figure 4 shows the design of the instrument. In order to make better use of the space, the two electric motors with the reduction gears are inserted in a tube which is placed inside the drum. The fact that the moving contact of the slide-wire resistor is fixed at the drum with the paper and the design of the recorder without an air gap mean that the recording errors are of the same order of magnitude as the thickness of the recording line.

The recorder is inserted in a container which protects the recorder from the water. Figure 5 shows the design of the wire inlets and the hermetic sealing of the container top.

Testing of the instrument. In the laboratory tests, sets of resistors with resistances close to the actual resistance of thermistor operation (3.6 kohm) were connected in place of the sensors to the input of the instrument. The following tests were made.

1. The sensitivity of the recorders was measured as deviation from the resistance value of one of the sensors, at which deviation the shift of the recording line is twice as high as the noise strip. The sensitivity did not exceed 0.1 ohm for all sets tested; this corresponds to a change of less than 0.002°C in the temperature of an MMT-1 thermistor.

2. The time-dependent drift of the zero line was measured for 60-80 min; the drift of the zero line did not exceed the noise strip in all instruments tested.

3. The zero line drift resulting from the influence of external temperature changes upon the instrument did not exceed a value corresponding to 0.005°C at temperatures between -15 and +25°C for all instruments.

At temperatures from -1.5 to +8°C the drift of the zero line did not exceed the noise level.

4. The accuracy of the recordings was measured by establishing the value to be measured from a value slightly greater than the actual value and from a value slightly smaller. The magnitude of the variations did not exceed the noise.

Three instruments were tested under field conditions. The instruments were used to measure the heat flow through the bottom of the Arctic Ocean, the Black Sea, and the Issyk-Kul' Lake.

The instruments worked satisfactorily in the field tests. Therefore a network of stations could be built [4]. We estimated the instrument-dependent error of measurements of the heat flow at less than 10-15%.

USSR Academy of Sciences
O. Yu. Shmidt Institute of
Physics of the Earth

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